Monitoring of Layered Uranium Tailings
- Phase II

DSS File #15SQ.23241-5-1705
Contract No. OSQ85-00130

A Research Report prepared for:

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May 1986

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The assistance and cooperation of the staff and personnel of the Key Lake Mining Corporation, in making this research project possible is gratefully acknowledged.

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II
DSS FILE NO. 15SQ.23241-5-1705
CONTRACT NO. OSQ85-00130

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SECTION 1.0 - SUMMARY

This report covers the second phase of a study that has been carried out to obtain detailed information on the mineralogically-complex uranium tailings at the Key Lake operations in Northern Saskatchewan. The tailings are deposited using the sub-aerial method in a tailings facility that incorporates a filter blanket and underseal over the entire area and a pervious embankment to decant surface water and to prevent any ponding on the exposed tailings beaches. These features have been designed to achieve full consolidation and the control of seepage from the tailings while the mine is in operation. Approval to commence the study was obtained on August 14, 1985. Data collection commenced on May 31, 1985 and field observations were terminated on October 28, 1985.

The tailings storage facility incorporates instrumentation to monitor the overall performance of the facility. This instrumentation is essentially external to the tailings itself and monitors the facility on a macro-scale. However, the opportunity existed to determine in detail the nature and behaviour of the actual tailings during deposition, and to generate information required for long term predictions. This gave rise to a two phased monitoring study under the auspices of the National Uranium Tailings Program. The results of Phase II of the study are presented in this report. Results of the Phase I study are briefly summarized in Section 2.3.

Monitoring installations for the Phase I study included two instrumented test sites (Site A and Site B) within the tailings facility, which were reactivated for Phase II. Site A contained a separate underdrain and seepage recovery system with automatic data logging equipment to record atmospheric data and tailings physical data. Continuous recording was supplemented with site visits to measure additional physical data. Also, tailings and seepage samples were collected for chemical and mineralogical characterization of the tailings. Soil materials used in construction of the facility were also sampled. Additional on-site laboratory test work included evaluation of freeze-thaw effects.

Data accumulation for Phase II at the two test sites included the following parameters:

	Site A	Site B
- atmospheric conditions	x	
- snow cover and ice thickness	x	x
- tailings temperature profiles	x	x
- pore pressures within the tailings	x	
- tailings moisture content and density	x	
- seepage water analyses	x	
- incoming tailings water analyses	(whole facility)	
- radon emanation	x	
- gamma radiation	x	x

Data accumulation from the site was reasonably effective, although ongoing difficulties were experienced with the data logging equipment and several sensors, and a nuclear density probe used for measuring moisture content and density. Continuously recorded data were collected from August 26, 1985 to October 28, 1985. Field observations and other relevant data were obtained during five site visits made between late May and late October.

Thermogravimetric test work carried out on Key Lake tailings material indicated that non free water losses during sample drying at 105°C were not significant. Approximately a 5% weight loss due to gypsum dehydration occurred from previously vacuum dried tailings at temperatures up to 120°C and an additional 4 to 6% occurred from diverse sources as samples were heated into the 600°C to 700°C range.

A methanol filled pycnometer was used to confirm that the previously established value of 2.64 for tailings specific gravity is sufficiently accurate. Efforts to determine the sub-sieve size distribution of Key Lake tailings continue to be unsuccessful due to the inability of conventional and non-conventional techniques to disperse gypsum bonded agglomerations.

The effects of freeze-thaw cycles on tailings properties was demonstrated by laboratory testing. Potential water recoveries were significantly increased when freeze-thaw cycles were incorporated into standard laboratory settling tests and settling tests with simultaneous underdrainage. For settling tests the potential water recovery increased almost 2.5 times. For a settled test with underdrainage and two freeze-thaw cycles the recovery increased almost 60%. Enhanced water recovery from freeze-thaw consolidation of the tailings was accompanied by formation of an extremely porous skeletal structure and resulted in low bulk densities. The maximum dry density achieved from the settling tests was approximately 0.7 t/m^3 for a drained sample subjected to two freeze-thaw cycles, but without any external loading. Field observation indicated that the thawed and drained tailings were capable of significant volume reduction under relatively light loads as the skeletal structure collapsed.

A wide variation in tailings moisture and density was apparent both laterally and vertically throughout the facility. The average dry density observed in the field was 0.64 t/m^3 and the average moisture content was 134%.

Gamma radiation measurements obtained during 1985 were similar to those obtained in 1984. The observed range on the tailings surface was 1.1 to 7.0 mrad/hr. The highest readings were obtained during scans down the tailings beach under dry summer conditions.

Measurements of radon exhalation were higher than observed during Phase I monitoring, averaging 6.0 $Bq/m^2.s$ at the principal monitoring site. The higher flux was in line with the values predicted in the EIS for dry and cracked tailings which predominated during Phase II monitoring. One anomalously high reading of 64.3 $Bq/m^2.s$ on fresh tailings was well above previous measurements on similar tailings, and also well above predicted levels.

The chemical composition of the tailings solids was determined on 8 core samples taken from locations throughout the tailings facility. Several differences appeared in the average mineralogical composition of the 1985 samples as compared with the 1984 samples. The primary differences are that 1985 samples had a higher clay content and lower quartz content.

Mineralogical studies carried out on the core samples did not identify any new minerals but better defined the distribution of nickel, arsenic and radium. Much of the nickel is present as non-soluble sulphide (millerite and bravoite) and the arsenide gersdorffite. Some water soluble nickel occurs probably as a sulphate compound. Arsenic is present as the non leachable gersdorffite although it also occurred as a heavy metal arsenate (eg. calcium arsenate). The nickel/arsenic ratio is consistent between grain size fractions indicating a consistent mineralogy. Gypsum nodules also contain considerable nickel and arsenic in their shells. Radium compounds are sparingly soluble. Destruction of some clay minerals appears to occur in the mill and new clay minerals forming in the tailings area may incorporate nickel.

Analyses of porewater from eight core samples showed a wide variation. Measured values of pH ranged from 7.4 to 10.9, arsenic from 0.6 to 13.0 ppm, nickel from 85 to 355 ppb, uranium from 0.2 to 10 ppb, while Ra-226 ranged from 54 to 167 Bq/l. Major differences between Phase II and Phase I analyses include significant increases in several components including molybdenum, tungsten, radium, arsenic and nickel. Ra-226 is puzzling with the concentration being strongly pH dependent for the influent and effluent samples collected during both studies. For porewater samples the relationship is weak and appears to be reversed. Variations in porewater chemistry appear to be unrelated to the locations of the samples on the tailings beach. It should be noted that the analytical laboratories were different for each Phase, and that Phase II sampling was more representative of the entire facility and included material that had been subjected to freeze-thaw cycling.

To provide input to a model predicting the rate of any contaminant transport from the Key Lake tailings storage facility, distribution coefficients were determined for several key contaminants. The distribution coefficient is defined as the mass of solute (contaminant) per unit mass of soil, divided by the mass of solute per unit volume of porewater and may be used to quantify the ability of natural underlying soil layers to adsorb contaminants from the seepage. Samples of seepage were shaken with selected underlying soils to provide the data for determining the distribution coefficients. The results were somewhat erratic, but in general, values for arsenic, uranium and radium fall within the range reported in the literature. Several elements including manganese, strontium and cobalt showed no adsorption by the soils tested.

Natural hydrogeological parameters for the site, including hydraulic conductivities of the various underlying materials and measured hydraulic gradients, were combined with predicted seepage rates and measured distribution coefficients, to model travel times and probable concentrations of specific elements at the nearest groundwater discharge.

The travel time for unretarded contaminants including nickel, calcium and thorium isotopes is estimated to be 2.7 years. For attenuated contaminants such as arsenic, uranium, molybdenum, zinc and Ra-226, over 1,000 years are required for any contaminant to be observed at Wolf Lake. Considerable dilution is expected to occur when any seepage reaches the groundwater. Under worst case assumptions, any seepage will be diluted to about one third of its initial concentration. In practice much greater dilutions are expected. Travel times are summarized below:

SUMMARY OF TRAVEL TIMES FOR SHORTEST DISTANCE TO SURFACE WATER

	Mean (Year)	Range (Year)	
		Minimum	Maximum
Unretarded ions	2.7	-	-
As	3300	1600	7,400
U	1100	160	1,100
Ni	110	2.7	490
Mo	1400	870	2,700
Zn	2200	790	14,000
Ca	23	2.7	47
Th 230	280	2.7	830
Th 228, 232	78	2.7	210
Ra 226	1000	490	1,700

SECTION 2.0 - INTRODUCTION

2.1 OBJECTIVES AND TERMS OF REFERENCE

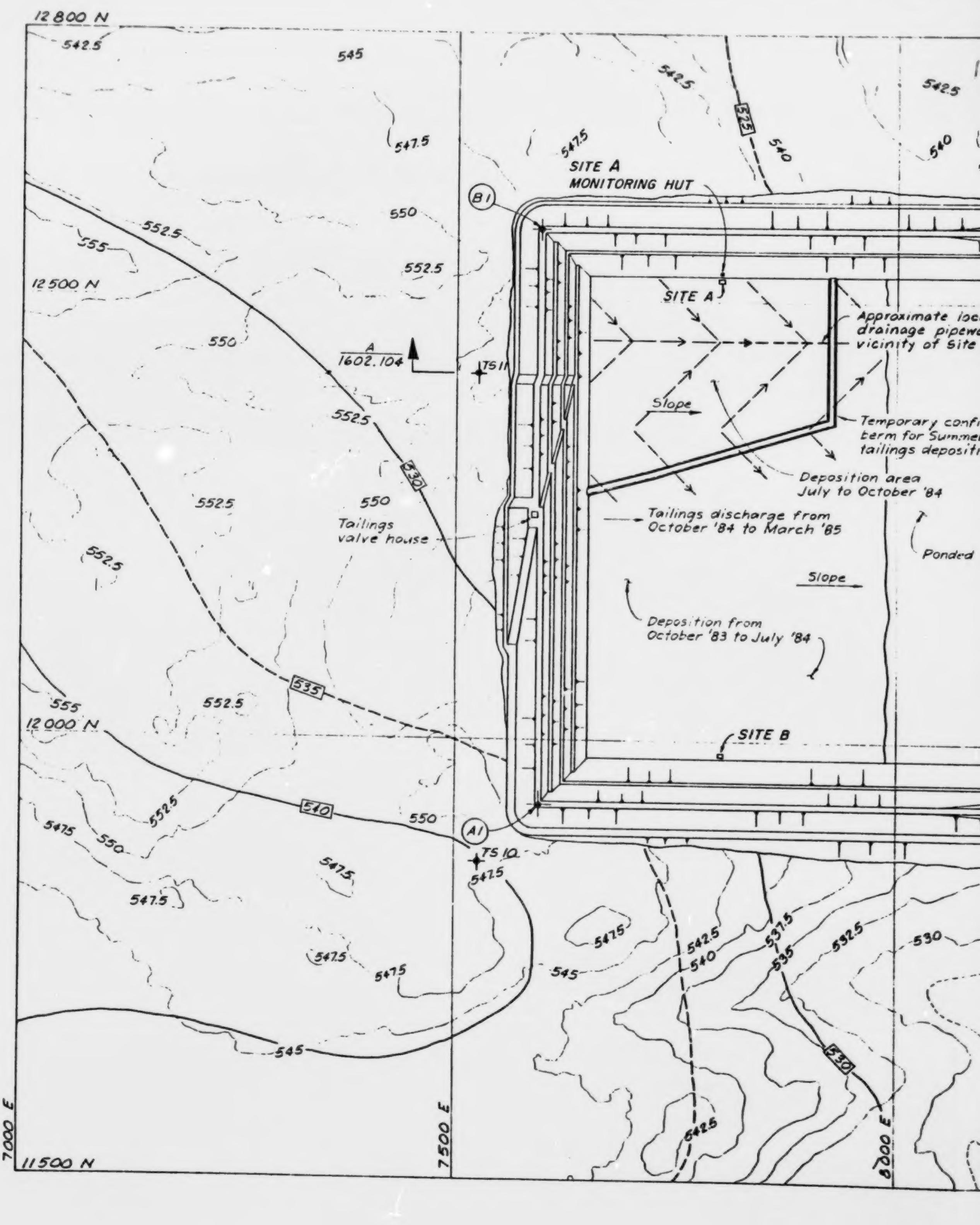
The basic objective of the Phase II monitoring study was to obtain additional information on the behaviour of the mineralogically-complex uranium tailings at the Key Lake Mining Corporation (KLMC) operations. The data would supplement that obtained during the Phase I study and support further predictions on the long term behaviour of these tailings deposited by the sub-aerial method.

The original statement of work for the Phase II study is included in Appendix AI. Authorization to proceed was obtained on August 14, 1985. In late October 1985 the Contract was ammended to include some further test work related to freeze-thaw properties of the tailings. The additional terms of reference are included in Appendix AII.

2.2 MONITORING INSTALLATIONS AND STUDY OUTLINE

An overall description of the KLMC operation is included in Section 2.1 of the Phase I report. The principal results of the Phase I report are summarized in Section 2.3 of this report. Design features of the tailings storage facility and locations of test sites are indicated on Figures 2.1 and 2.2.

Monitoring installations for the study were located at two sites in the tailings storage facility, Site A and Site B (Photograph Nos. 1 and 2). Site A contained an impervious liner and sump pump beneath the tailings and was instrumented for continuous measurement and recording of atmospheric and tailings physical data using a data logger. Site B was used in conjunction with Site A for periodic visual observations and measurement of several tailings parameters. Parameters measured during the Phase II study included:


12 800 N
12 500 N
12 000 N
11 500 N
7000 E
7500 E
8000 E
542.5
545
547.5
550
552.5
555
540
535
530
537.5
532.5
SITE A
MONITORING HUT
SITE A
SITE B
B1
A1
A
1602.104
TS 11
TS 10
Approximate loc
drainage pipew
vicinity of Site
Slope
Slope
Temporary confi
berm for Summe
tailings depositi
Deposition area
July to October '84
Tailings discharge from
October '84 to March '85
Tailings
valve house
Ponded
Deposition from
October '83 to July '84
Scale
100

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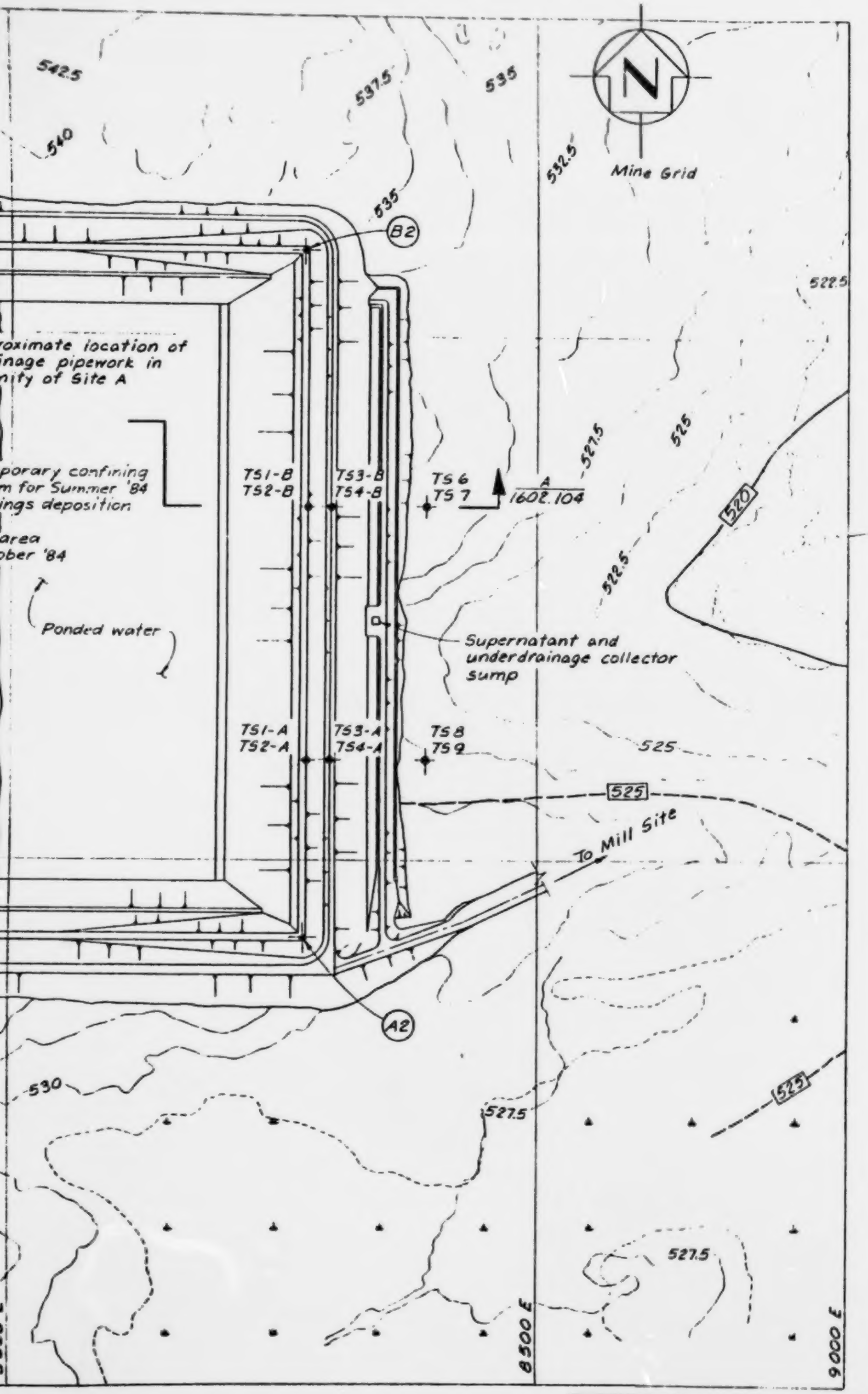

542.5
540
537.5
535
532.5
N
Mine Grid
535
B2
522.5
...roximate location of
...inage pipework in
...nity of Site A
...porary confining
...m for Summer '84
...ings deposition
...area
...ober '84
Ponded water
TS1-B
TS2-B
TS3-B
TS4-B
TS 6
TS 7
A
1602.104
527.5
525
520
522.5
To Wolf Lake
Supernatant and
underdrainage collector
sump
TS1-A
TS2-A
TS3-A
TS4-A
TS 8
TS 9
525
525
To Mill Site
A2
530
527.5
525
527.5
8500 E
9000 E

LEGEND

Ⓐ1 Setting out points
═ ═ Groundwater table contours
TS1-A ✦ Standpipe piezometers for regional groundwater monitoring.
ѱ Muskeg

Notes

1. All elevations are in metres

Scale 100 50 0 100 200 300 m

...VED	REV.	DATE	DESCRIPTION	APPROVED

REVISIONS

KNIGHT AND PIESOLD LIMITED
CONSULTING ENGINEERS – VANCOUVER, B.C.

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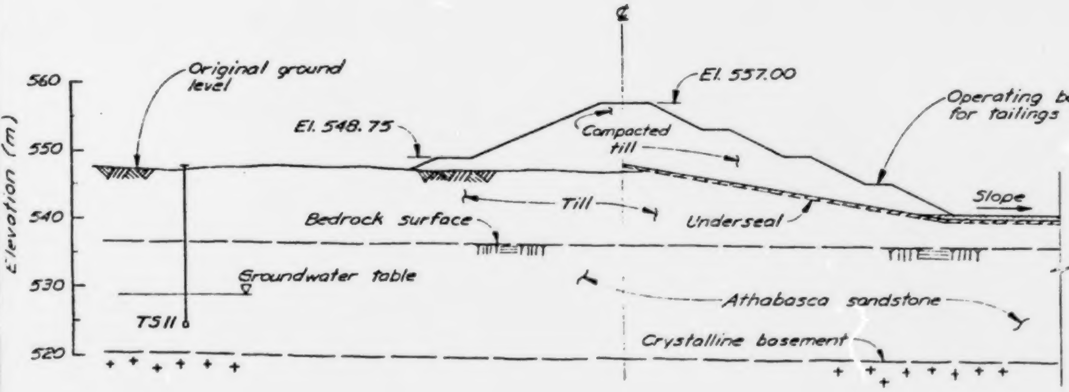
CHECKED JMHaine
APPROVED JMHaine

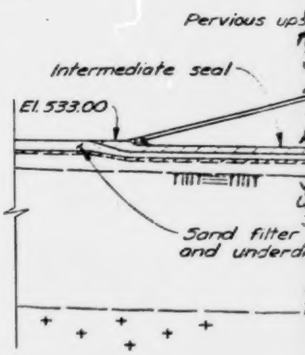
SUPPLY AND SERVICES CANADA
MONITORING OF LAYERED URANIUM TAILINGS
PHASE I

TAILINGS STORAGE FACILITY
GENERAL ARRANGEMENT

DATE APRIL 4, 1985 | SCALE AS SHOWN | DRG. NO. 1602.103 | REV.

FIGURE 2.1


℄
560
550
540
530
520
Elevation (m)
Original ground level
El. 557.00
El. 548.75
Compacted till
Operating bench for tailings deposition
Slope
Till
Underseal
Bedrock surface
Groundwater table
TS11
Athabasca sandstone
Crystalline basement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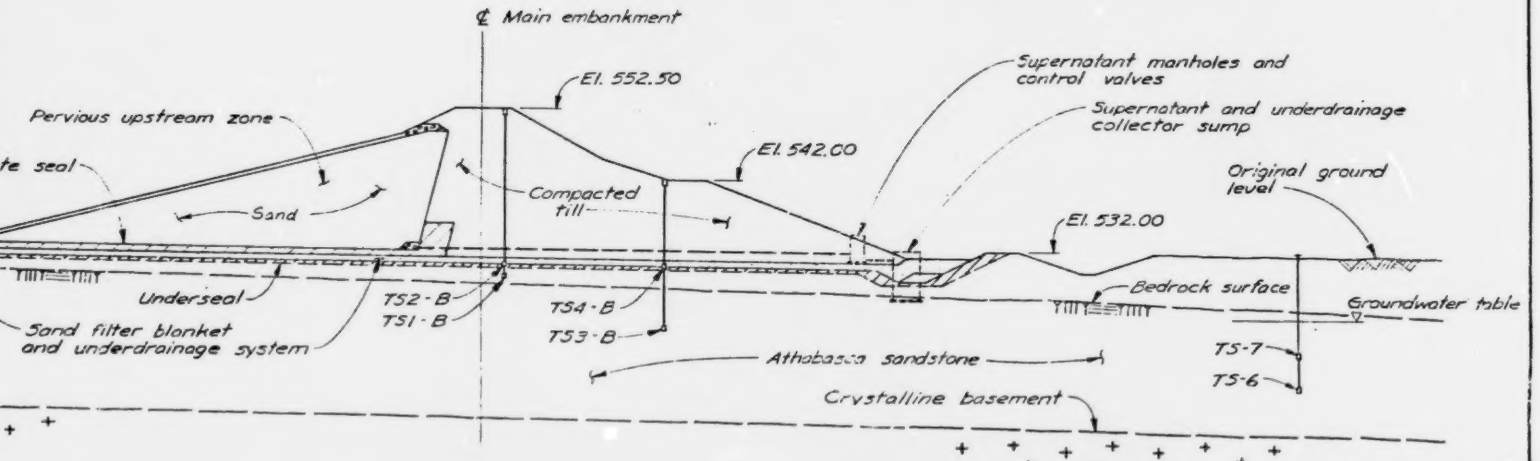
℄ Main embankment
El. 552.50
Pervious upstream zone
te seal
El. 542.00
Supernatant manholes and control valves
Supernatant and underdrainage collector sump
Original ground level
Compacted till
Sand
El. 532.00
Underseal
Bedrock surface
Groundwater table
Sand filter blanket and underdrainage system
TS2-B
TS1-B
TS4-B
TS3-B
Athabasca sandstone
TS-7
TS-6
Crystalline basement

SECTION $\frac{A}{1602.103}$

NOTE

All elevations are in metres.

Scale 10 5 0 10 20 30 40 50 m

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		REVISIONS		

KNIGHT AND PIESOLD LIMITED
CONSULTING ENGINEERS – VANCOUVER, B.C.

DESIGNED
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CHECKED
APPROVED

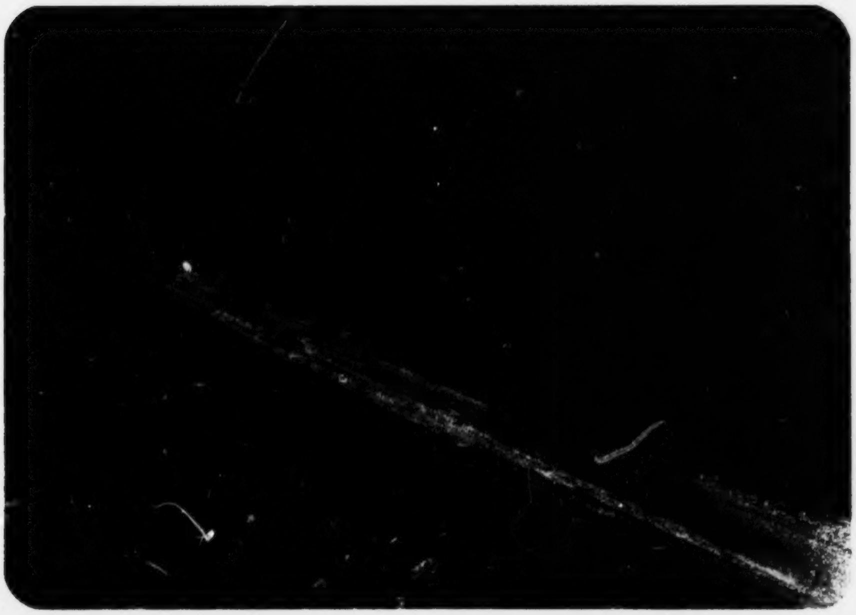
SUPPLY AND SERVICES CANADA
MONITORING OF LAYERED URANIUM TAILINGS
PHASE I

TAILINGS STORAGE FACILITY
TYPICAL CROSS-SECTION

DATE APRIL 4, 1985 | SCALE AS SHOWN | DRG. NO. 1602.104 | REV.

FIGURE 2.2

Photograph No. 1 Monitoring hut and instrumentation at Site A, June, 1985. View towards west embankment and tailings discharge pipework.



Photograph No. 2 Tailings discharge along south side of facility, June, 1985. Site B access scaffold located left centre.

- atmospheric conditions
- snow cover and ice thickness
- tailings temperature profiles
- pore pressures within the tailings
- tailings moisture content and density
- radon emanation from the tailings surface
- gamma radiation

Monitoring installations were generally reinstalled in early June 1985 although instrument failure precluded any significant data collection until late August 1985. Specific details of data and sample accumulation methods not described in the Phase I report are given in Section 3.0.

In July 1985, samples of tailings were extracted from 8 locations in the facility for laboratory test work. Also collected for the test work were seepage from the tailings and samples of the sand, till, bentonite and sandstone which make up the construction materials, and natural materials underlying the facility. The test work consisted of:

- determination of mineralogical characteristics of the tailings.
- chemical analyses of the contained porewater.
- chemical analyses of the tailings solids and of the construction materials.

- determination of distribution coefficients for significant ions contained in the seepage with respect to both engineered and natural underlying materials.

- use of the distribution coefficients to model contaminant migration and attenuation for seepage through the underseal of the tailings storage facility.

- thermogravimetric analyses (TGA) and differential scanning calorimetry (DSC) evaluation of tailings material to determine non free moisture weight loss.

- determination of particle size distributions.

- evaluation of freeze-thaw behaviour of tailings material.

Chemical analyses and distribution coefficient test work was carried out by Chemex Labs Ltd. of Vancouver.

Mineralogical characterization of tailings solids and some aspects of freeze-thaw evaluations were carried out by Saskatchewan Research Council.

TGA and DSC work was carried out by B.C. Research.

Non standard particle size distribution determinations were attempted by B.H. Levelton and Associates of Vancouver.

Review of the tailings physical and chemical data, radiation measurements and determination of distribution coefficients was carried out by Senes Consultants Ltd. of Willowdale, Ontario, who prepared Section 7, 8 and 9 of this report.

Work on freeze-thaw behaviour, physical characterization of tailings and contaminant transport modelling was carried out by Knight and Piesold Ltd.

A schematic outline of the study is shown on Figure 2.3.

2.3 SUMMARY OF PHASE I RESULTS

The following summary is abstracted from Section 1.0 of the Phase I report.

Data was accumulated at two test sites and included the following parameters:

	Site A	Site B
- atmospheric conditions	x	
- snow cover and ice thickness	x	x
- tailings temperature profiles	x	x
- pore pressures within the tailings	x	
- tailings moisture content and density	x	x
- seepage flows and analyses	x	
- surface run-off analyses	x	
- incoming tailings water analyses	(whole facility)	
- radon emanation	x	x
- gamma radiation	x	x

Data were collected from October 1984 to March 1985.

Physical data recorded for the tailings enabled a reasonable explanation of the observed tailings behaviour to be undertaken. The tailings at Site A were deposited over a short period of time in the summer of 1984 to a depth of 2 metres. Initial excess pore pressures were observed with subsequent drainage and the development of suction pressures throughout the tailings by

MONITORING OF LAYERED URANIUM TAILINGS
PHASE II

STUDY OUTLINE

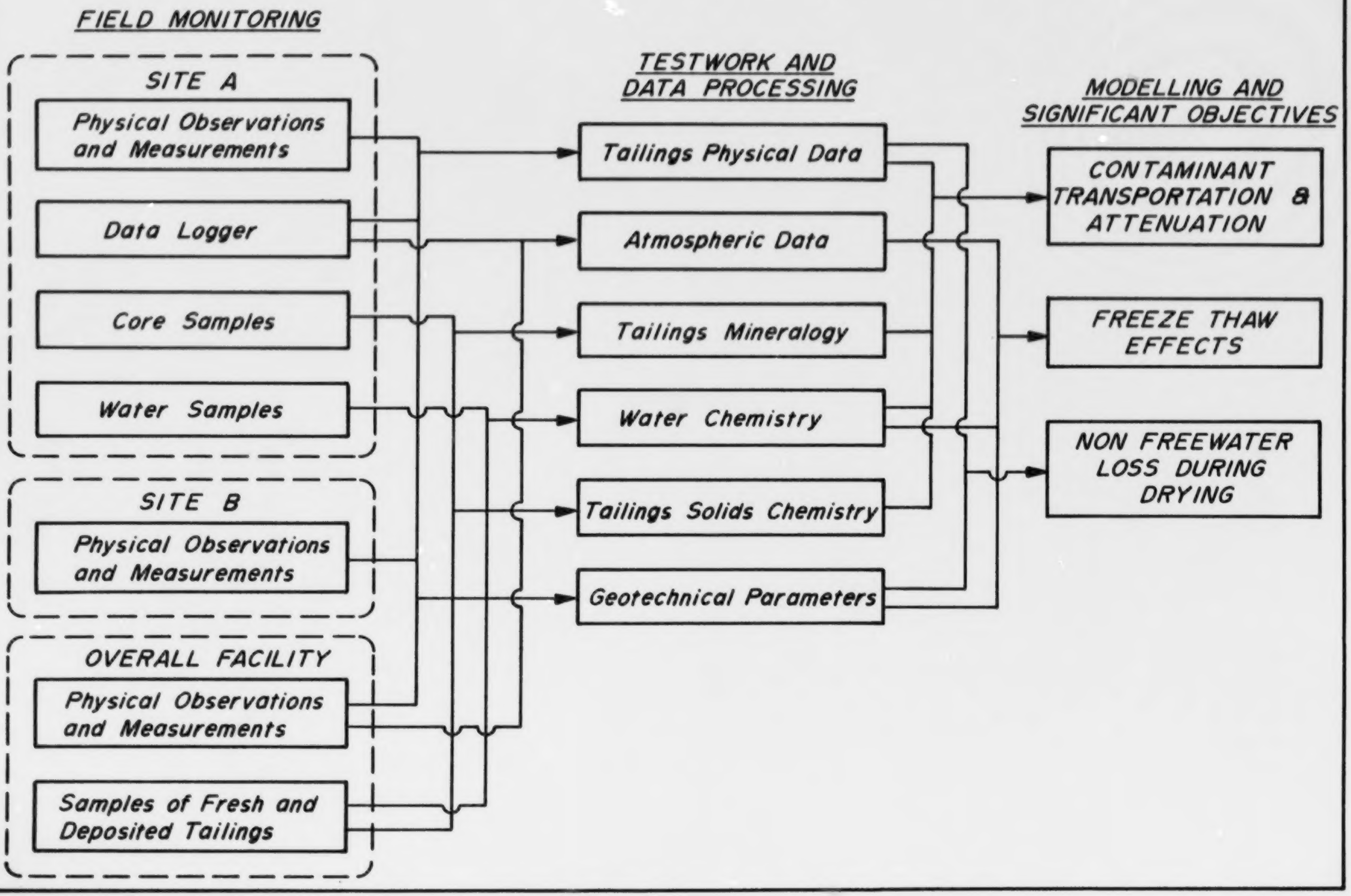

FIELD MONITORING
SITE A
Physical Observations and Measurements
Data Logger
Core Samples
Water Samples
SITE B
Physical Observations and Measurements
OVERALL FACILITY
Physical Observations and Measurements
Samples of Fresh and Deposited Tailings
TESTWORK AND DATA PROCESSING
Tailings Physical Data
Atmospheric Data
Tailings Mineralogy
Water Chemistry
Tailings Solids Chemistry
Geotechnical Parameters
MODELLING AND SIGNIFICANT OBJECTIVES
CONTAMINANT TRANSPORTATION & ATTENUATION
FREEZE THAW EFFECTS
NON FREEWATER LOSS DURING DRYING

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FIGURE 2.3

January 1985. Recorded densities in the tailings were relatively low and in the order of 0.5 t/m^3. Frost penetration over the winter was in the order of 500 mm.

In general, physical parameters measured for the tailings indicate that the behaviour was significantly influenced by the gypsum and other precipitates which constitute up to 30 percent of the total solids. Fairly low densities were recorded in the order of 0.5 t/m^3 at Site A and 0.65 t/m^3 at Site B. However, these values were specific to the monitoring sites and did not necessarily reflect average annual values for the whole facility. They may also have been influenced in part by abnormal operation of the facility after start-up, when only part of the full area was available for tailings deposition.

In the laboratory, saturated permeability values for the tailings were measured in the order of 1 x 10^{-7} m/s, with a reduction of approximately one order of magnitude after consolidation under the anticipated full depth of tailings. Of major significance was the reduction in permeability that occurred once suction pressures were developed and the material became unsaturated. A reduction of up to four orders of magnitude ($k < 1 \times 10^{-11}$ m/s) was measured for a suction pressure of 1 metre of water. This characteristic would have a significant impact on reducing the movement of water through the tailings once unsaturated conditions have been established.

Measurements of gamma radiation and radon exhalation rates agreed with previous predictions. Given the high moisture content of the tailings, both gamma fields and radon emissions were low. Measured values of gamma radiation ranged from 1.4 to 2.8 mrad/hr and radon emanation rates were found to agree well with rates predicted in the EIS, with a value of 2.1 Bq/m^2. sec for a wet tailings beach. Neither is of major concern in the long term as the area is to be capped with an engineered cover.

This study produced a good understanding of the chemical and radiological properties of the Key Lake tailings solids and liquids. As a result of the leaching study and the geochemical modelling, reasonable predictions of the long term seepage quality from the tailings deposit were made.

In general, the Key Lake uranium tailings are mineralogically very different from uranium tailings encountered elsewhere in Canada in that they are non-acid generating, and contain a significant proportion of gypsum and clays.

Detailed seepage modelling was carried using a transient finite element seepage program developed by the University of Saskatchewan. This modelling indicated that the tailings material became the major barrier to significant moisture movement once partial saturation occurs and suction pressures are developed, due to the very significant resulting decrease in permeability. Best estimates of potential total seepage from the base of tailings were approximately 50 m^3/yr at the end of operations and less than 10 m^3/yr in the long term (300 to 500 years) after decommissioning. These values are insignificant and considerably lower than the detection limits of the underdrainage and monitoring systems. For comparison, a conventional wet disposal system of equivalent area relying on a containment seal with a permeability of 1×10^{-8} m/s could produce seepage in excess of 10,000 m^3/yr at the end of operations.

Measurements of seepage collected at Site "A", the extensively instrumented site, showed that the pH ranged from 7.1 to 7.4, lower than the incoming and surface runoff pH of over 11. The principal constituents of the seepage were calcium and sulphate at the saturation level of gypsum. Concentrations of all significant metals in the seepage were low at less than 1 mg/L. The only radionuclide at significant levels in the seepage was Ra-226 at 12 and 45 Bq/L. This compared with Ra-226 values for the whole facility measured at 2.6 to 25 Bq/L, mean 7.1 Bq/L.

Porewater was extracted from cores taken from both test sites. The pH of the porewater ranged from 9.3 to 11.1. Arsenic levels ranged from 0.3 to 2.2 mg/L and Ra-226 ranged from 10 to 55 Bq/L. Uranium levels were very low at less than 0.005 mg/L. Simple washing tests were done on two dewatered cores. Wash ratios of 4:1 (water/solids) in three stages were selected to approximate the maximum possible infiltration of water over 1000 years. Under these test conditions, the pH of the wash water was shown to decrease from alkaline to neutral and the concentrations of Ra-226 and arsenic increase with increasing wash ratio.

The environmental effects of the potential seepage in terms of water quality degradation or radioactive dose to man would depend upon the seepage flow path, dilution, natural retardation processes and the location of potential receptors. Seepage volume was predicted to be low during operation and in the long term after facility decommissioning. Concentrations of contaminants in the seepage would depend on interactions with barrier materials.

SECTION 3.0 - ACCUMULATION METHODS

3.1 GENERAL

The instrumentation used for gathering the data for this Phase II report was described in detail in the first phase report "Monitoring of Layered Uranium Tailings - Phase I", DSS File No. 26SQ.23241-4-1679, May 1985.

This section describes only those modifications to the equipment, methods and sampling locations that were particular to the second phase of the study, or have not previously been described.

Actual field data and results of analyses and tests carried out on field samples are reported in subsequent sections under the relevant topics.

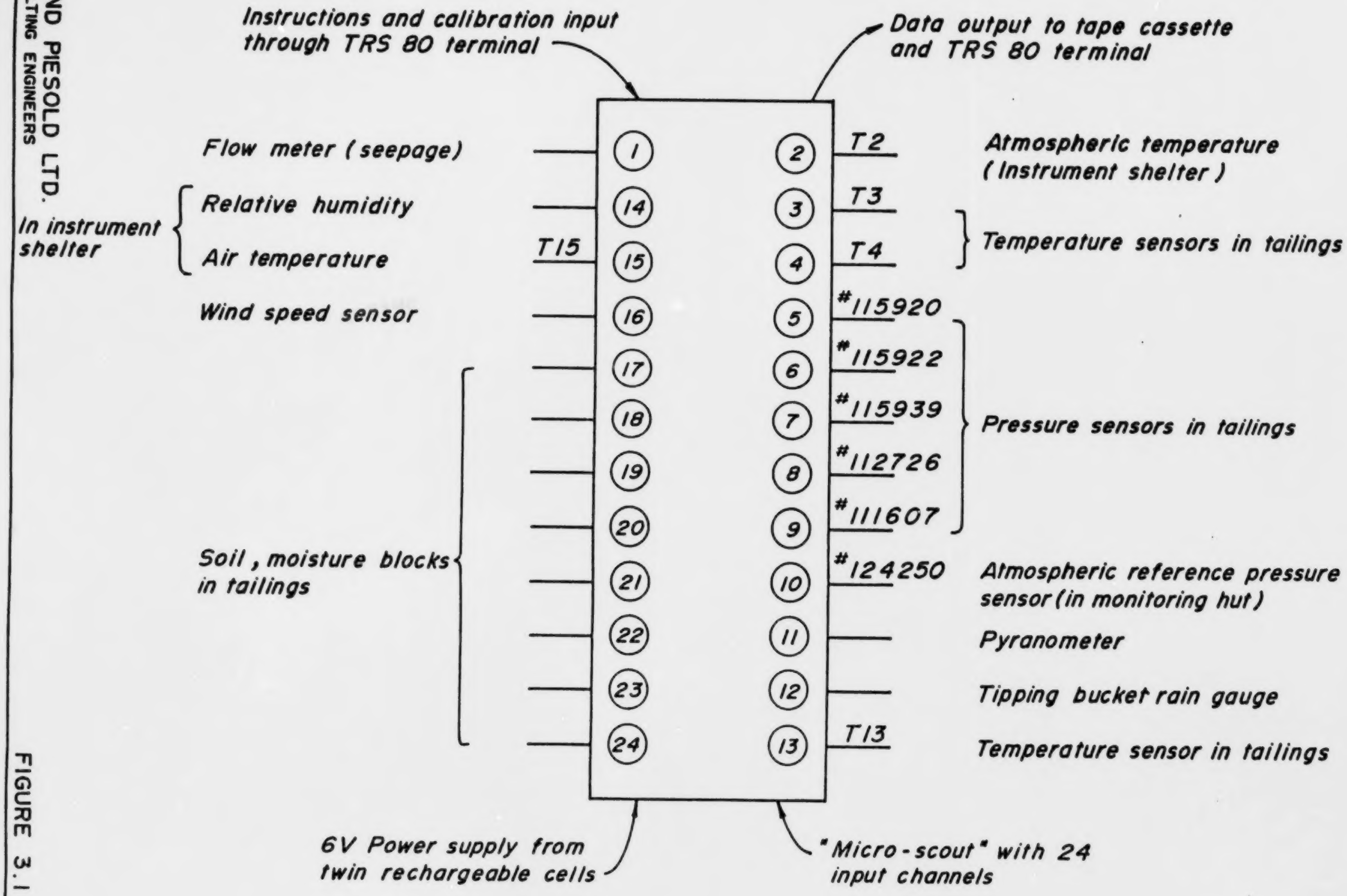
3.2 CONTINUOUS MONITORING EQUIPMENT

The "Microscout" data logger installed to monitor sensors in or adjacent to Site A was upgraded to include 48K of RAM memory and the ability to monitor 24 sensors. A schematic of the data logger showing the channel to which each sensor was connected is included as Figure 3.1, with the additional channels 17 to 24 being used for monitoring moisture blocks (See Section 3.2.2).

The data logger was reinstalled on June 1, 1985. During the first monitoring period a total data loss occurred due to an excessive power consumption and an unrelated failure of the central processing unit (CPU) of the data logger. The data logger was removed from the site for repair on July 15, 1985. At the same time updating of the firmware was carried out to allow easier checking of sensor data without interruption of the monitoring programme. This modification inadvertantly resulted in the loss of capability for monitoring wind speed. The data logger was again returned to service on

MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

INSTRUMENTATION CONNECTED TO "MICRO - SCOUT" DATA LOGGER



Instructions and calibration input through TRS 80 terminal
Data output to tape cassette and TRS 80 terminal
Flow meter (seepage)
In instrument shelter
Relative humidity
Air temperature
T15
Wind speed sensor
Soil , moisture blocks in tailings
1
14
15
16
17
18
19
20
21
22
23
24
2
3
4
5
6
7
8
9
10
11
12
13
T2
T3
T4
#115920
#115922
#115939
#112726
#111607
#124250
T13
Atmospheric temperature (Instrument shelter)
Temperature sensors in tailings
Pressure sensors in tailings
Atmospheric reference pressure sensor (in monitoring hut)
Pyranometer
Tipping bucket rain gauge
Temperature sensor in tailings
6V Power supply from twin rechargeable cells
"Micro - scout" with 24 input channels

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FIGURE 3.1

August 26, 1985. Data collection continued satisfactorily from most channels until October 28, 1985.

Experience with the data logger over several seasons indicates that such equipment has tremendous capability when working well. However each "upgrading" of the unit resulted in new problems and failures mostly of the system electronics and firmware/software but also with the associated sensors and as a result of operator error.

In part these problems are due to the greater capability and complexity of the units and responses of the supplier to demands of numerous users. Unfortunately the discovery of "bugs" and component failures accompanying the upgrading results in loss of data to the end user. Where field visits are scheduled at long intervals and data loggers must be removed from service for correction, data loss may span significant periods.

3.2.1 Pore Pressure Transducers

The pore pressure transducers at Site A which were monitored during the Phase I study were replaced under warranty due to their excessive and unquantifiable drift and mechanical failure of check valves used in the flushing leads. As reported in the Phase I study the data collected was of value in indicating pore water pressure trends and changes, but not actual pressures.

When several of these sensors were removed from the tailings, the filter stones were observed to have broken off cleanly along the line of an epoxy joint to the plastic pipe body encasing the unit. This was attributed to either freezing of the flushing water or to the different thermal expansion coefficients of epoxy, plastic and filter ceramic.

Replacement transducers, supplied under warranty, were Druck type PDCR 10/D which are of the integrated silicon strain gauge bridge type.

The specifications for the transducers used for Phase II were:

Pressure Range:	-7.0 to + 7.0 m water (-10 to + 10 psia) (one unit supplied with a 15 psi range)
Accuracy:	±0.3% to ±0.75% over a -2°C to +30°C temperature range. (Actual value depended on individual sensor).
Maximum Pressure:	Rated pressure able to be exceeded by a factor of 4 causing negligible calibration change.

Each sensor was sealed at sea level at a known atmospheric pressure. This was done to avoid potential problems due to freezing of condensed water where the atmospheric compensation leads crossed the frost line. Coors filter stones were fitted to five of the sensors, which were saturated with tap water by boiling, prior to their burial in the tailings mass as recommended by the supplier. The sixth sensor, without a stone, was placed in the monitoring hut to serve as an atmospheric reference.

Flushing leads were not installed because of previous experience and anticipated on-going difficulties with freezing of the leads at the frost line. The short project duration, expected low soil suctions, and imminent placement of further tailings over the test site, which would result in positive pore pressures, lead to the decision that prior saturation of the Coors stones would be sufficient to maintain full saturation of the piezometer tips.

No loss or change of calibration occurred as a result of boiling the pressure sensors to achieve saturation, even though most stones developed fine hair line cracks down their length.

The installation elevation of each sensor installed in the tailings is given below, with the locations shown on Figures 3.2 and 3.3.

Pressure Sensor	Data Logger Channel	Tip Elevation at Installation (m)	Height Above Filter Blanket (mm)	Depth Below Surface (Oct. 26 estimated) (mm)
115920	5	539.65	250	1850
115922	6	540.15	750	1350
115939	7	540.65	1250	850
112726	8	539.90	500	1600
111607*	9	540.40	1000	1100
124250	10	543.50	Reference	Reference

*This unit has ±15 psi range all others have ±10 psi range.

As discussed in Section 5.2 all the buried sensors appeared to respond to changes in tailings pore pressures. Because of the longer than anticipated time delay between burial of the sensors and placement of fresh tailings, air entry into some of the stones is probable and this may have resulted in some error in reading negative pore pressures. The hair-line cracking of the stones may have worsened this problem.

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MONITORING OF LAYERED URANIUM TAILINGS

PHASE II

SCHEMATIC OF MONITORING INSTALLATIONS - SITE A

LEGEND

SP	Standpipe piezometer	MD	Access tube for nuclear moisture / density probe
W	Wind instrument		
P	Electric piezometer and moisture block mast	T	Temperature probe mast

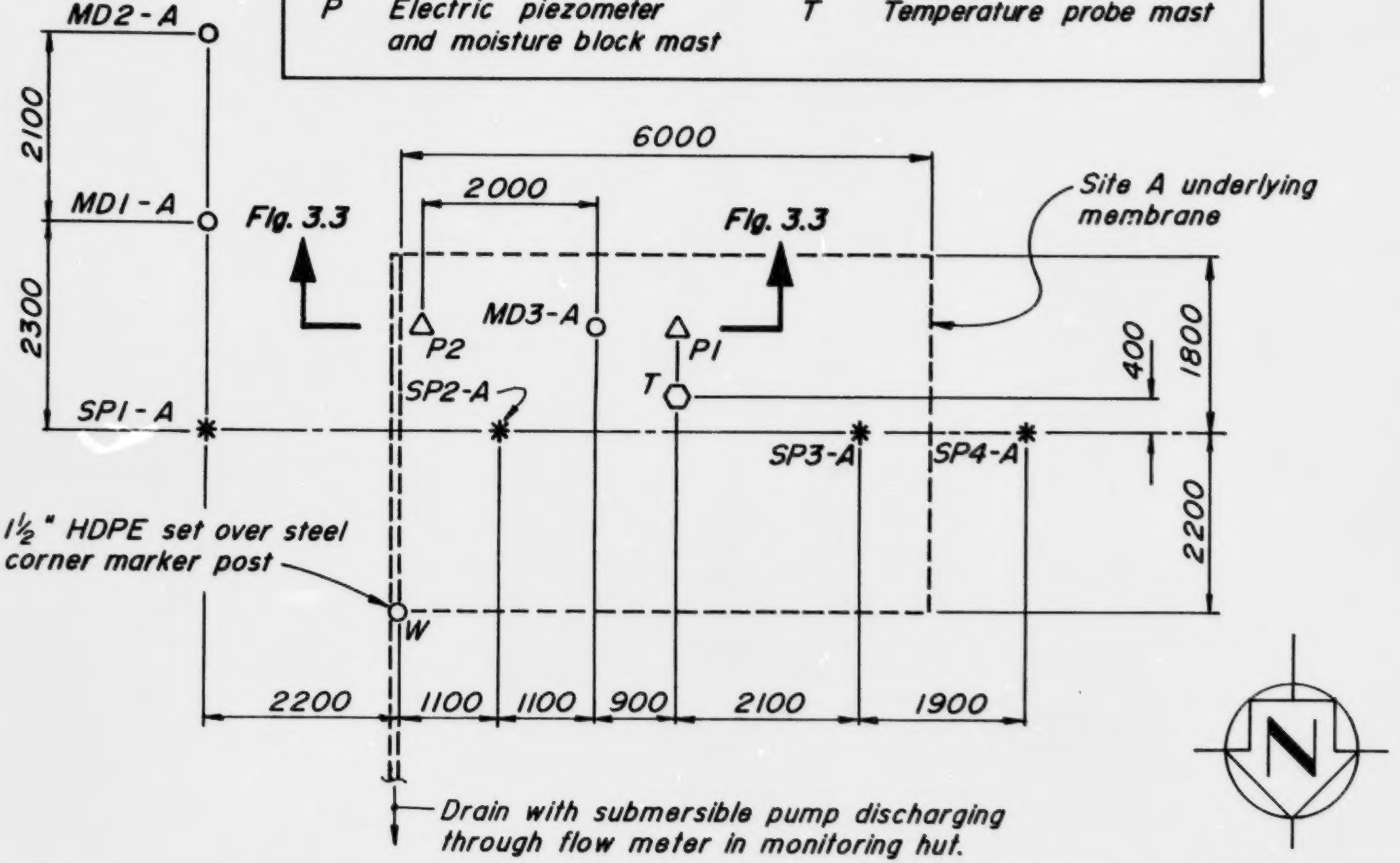
MD2 - A
2100
MD1 - A
2300
SP1 - A
Fig. 3.3
Fig. 3.3
6000
2000
MD3 - A
P2
P1
T
SP2 - A
SP3 - A
SP4 - A
Site A underlying membrane
400
1800
2200
1½" HDPE set over steel corner marker post
W
2200
1100
1100
900
2100
1900
N
Drain with submersible pump discharging through flow meter in monitoring hut.

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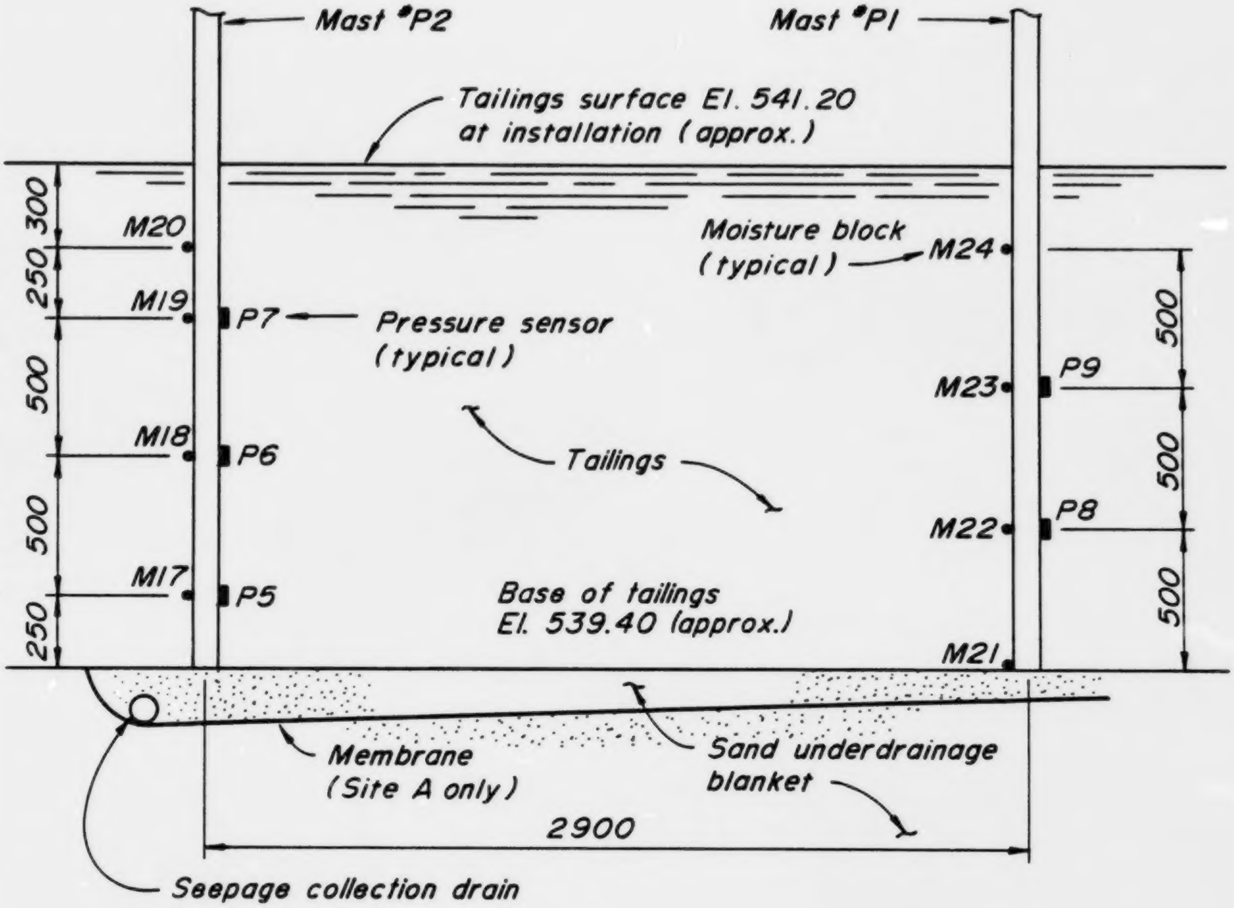
FIGURE 3.2

MONITORING OF LAYERED URANIUM TAILINGS
PHASE II

SCHEMATIC OF MONITORING INSTALLATIONS - SITE A
SECTION I


Mast #P2
Mast #P1
Tailings surface El. 541.20 at installation (approx.)
300
250
500
500
250
M20
M19
M18
M17
P7
P6
P5
Pressure sensor (typical)
Moisture block (typical)
M24
M23
M22
M21
P9
P8
500
500
500
Tailings
Base of tailings El. 539.40 (approx.)
Membrane (Site A only)
Sand underdrainage blanket
2900
Seepage collection drain

LEGEND

P7 Pressure sensor connected to data logger channel 7

M23 Moisture density block connected to data logger channel 23

For temperature mast elevations see Figure 5.4

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FIGURE 3.3

3.2.2 Moisture Blocks

Eight soil moisture blocks were installed at Site A, along with the pressure sensors, in order to further monitor the changing water content of the tailings mass. The blocks, which are extensively used in agriculture to monitor soil moisture content, consist of small, precisely dimensioned co-axial electrodes embedded in a small block of gypsum.

The moisture content of soil can be related to the resistance in the sensor. When the block is wet, the resistance is low, and as the block dries, the resistance increases, indicating a fall in soil moisture content.

The blocks are inexpensive and potentially a useful tool particularly if accurately pre-calibrated against the soil being monitored. For the Key Lake tailings where the porewater is saturated with gypsum the supplier indicated some probability of a relatively short service life. Because the distance between each block and the data logger was unusually long at approximately 100 feet additional sensitivity problems might be expected due to the weak signal received at the data logger.

In practice the blocks provided no information of value during the project due to a failure of the signal conditioning unit servicing them and to a previous total data loss from the data logger.

The elevations at which the blocks were installed are indicated below and shown on Figures 3.2 and 3.3.

Moisture Block Channel No.	Elevation at Installation (m)	Height Above Filter Blanket (mm)	Depth Below Surface (Oct. 26 (estimated) (mm)
17	539.65	250	1850
18	540.15	750	1350
19	540.65	1250	850
20	540.90	1500	600
21	539.40	0	2100
22	539.90	500	1600
23	540.40	1000	1100
24	540.90	1500	600

3.3 CORE AND TAILINGS SAMPLING

Eight tailings samples were collected from within the tailings facility in July 1985 and used for porewater analysis and solids chemical and physical analyses. Sub-samples were taken for thermogravimetric analysis and differential scanning calorimetry, particle size determination and mineral identification.

The samples were composited from material collected at several elevations in spade holes made in the top 1 metre of tailings at each sampling location. Samples were taken on two lines running from east to west down the centre of the north and south sides of the facility, being designated B1 to B4 for the south side and A1 to A4 for the north side. Locations are shown on Figure 3.4. Each sample was triple bagged in plastic and placed in an individual marked clean plastic pail with a sealed lid. Sub-sampling was carried out by Chemex Labs.

A search was made for ice lenses at each sampling location.

Additional core samples were taken at Site A during each site visit to monitor variations in soil moisture and density.

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MONITORING OF LAYERED URANIUM TAILINGS
PHASE II

LOCATION OF TAILINGS DISCHARGE AND TAILINGS SAMPLES

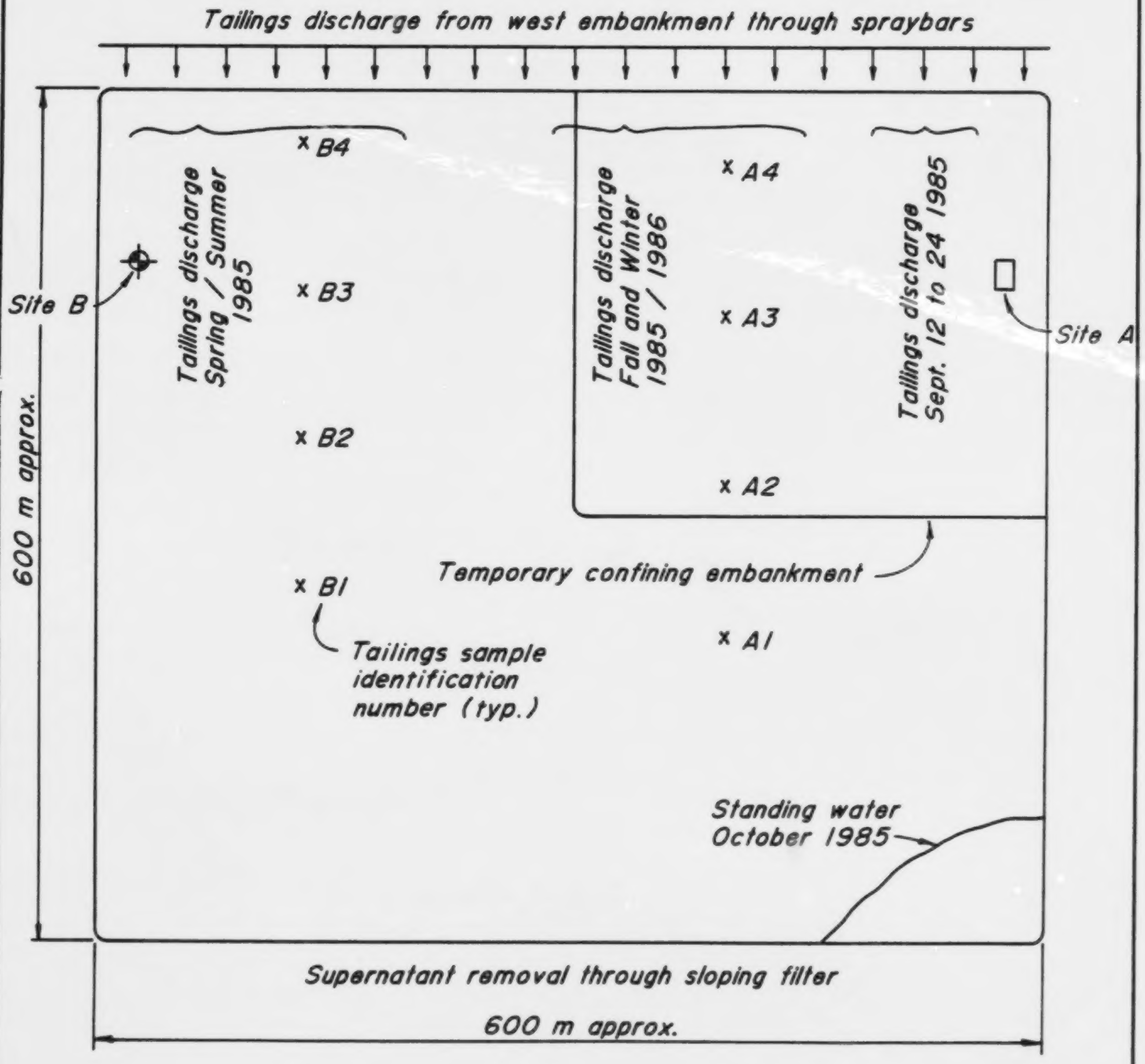
Tailings discharge from west embankment through spraybars
Site B
Tailings discharge Spring / Summer 1985
B4
B3
B2
B1
Tailings sample identification number (typ.)
Tailings discharge Fall and Winter 1985 / 1986
A4
A3
A2
A1
Tailings discharge Sept. 12 to 24 1985
Site A
Temporary confining embankment
Standing water October 1985
Supernatant removal through sloping filter
600 m approx.
600 m approx.

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FIGURE 3.4

Fresh tailings material was collected in late October by drawing off tailings pump discharge into clean pails in order to investigate, on site, the freezing and thawing properties of tailings.

3.4 SITE A FLOW MONITORING

At the conclusion of Phase I monitoring the seepage collection pump discharge pipework for Site A including the flow meter was flushed clean and drained. The discharge pump was left in the automatic operation mode.

The electrical cable to the hut was severed during March 1985 and was not repaired until late May 1985. No flow was pumped during the tailings thaw or rain storm events during that time.

3.5 WATER AND SOIL SAMPLING

Seepage water, pumped from the filter blanket underneath Site A was collected in July 1985, together with sand, till and sandstone that form part of, and underlie the facility, for use in retardation coefficient determinations. Bentonite similar to that used during construction of the facility was obtained from the original supplier. Sand and till material was sampled within the facility at locations remote from any contact with tailings or tailings water. Sandstone chips were obtained from boulders and rock outcrops removed during construction.

Soil samples were double bagged in plastic and packed in new plastic pails with sealed lids.

The seepage water for shaker tests was pumped from the collector drain under Site A into new plastic carboys that had previously been acid washed, and rinsed with seepage water. No site filtration was carried out. Preservatives were not added.

Between late March 1985 and sample collection in July 1985 no fresh tailings were placed over Site A. The sump pump was activated once only, in May when it was necessary to manually start the pump because the sump was not full. The seepage collected for the shaker tests was not from freshly placed tailings and may have been diluted by infiltration.

An additional seepage sample was collected from Site A in September 1985 in conjunction with the test programme to evaluate freeze-thaw properties of tailings.

3.6 ANALYTICAL LABORATORIES AND PROCEDURES

It should be noted that chemical analyses for Phase I were carried out at Saskatchewan Research Council, while those for Phase II were carried out by Chemex Labs in Vancouver. Detailed laboratory procedures are presented in Appendix C.

Filtration of samples for dissolved ion determinations was carried out using three micron filter papers for Phase I and also at three microns, followed by 0.45 microns for Phase II, except for Ra-226 determination where a subsample of the 3 micron filtrate was retained.

3.7 MOISTURE DENSITY GAUGE

Repairs carried out by the instrument supplier at the conclusion of Phase I were not satisfactory and the instrument continued to give inconsistent and non-reproducible data. Poorly repaired mechanical damage to threaded components continued to threaten loss of the probe containing the radioactive sources down a monitoring standpipe.

Three of the four standpipes at Site A, that had been pinched by frozen tailings the previous winter, were again able to accept the probe after the tailings had thawed.

The gauge has not proven useful for this project due principally to its poor mechanical/electronic performance and due to the logistical and practical difficulties of providing acceptable calibration for moisture and density. Calibration difficulties arise due to the heterogeneous nature of the layered Key Lake tailings with additional complexities resulting from freeze-thaw cycling.

Problems with the gauge were less apparent during Phase I, as many of the readings were made prior to significant freeze-thaw modification.

The requirements of "Transportation of Dangerous Goods Act" and the necessity for factory service also severely restrict the easy transport and repair of the instrument.

3.8 SITE B MONITORING

Due to the on-going deposition and build-up of tailings over Site B, access was not possible for Phase II and monitoring was restricted to reading of the buried temperature sensors and local gamma radiation determinations.

3.9 MISCELLANEOUS OBSERVATIONS

In addition to the detailed site observations made at each trip the following data was also collected using available instrumentation:

- Gamma radiation
- Radon flux
- Site A phreatic surface
- KLMC Climatological Station Data

SECTION 4.0 - ATMOSPHERIC DATA

4.1 GENERAL

Atmospheric data from the KLMC station is summarized on Table 4.1 together with the data available from the Site A instruments. Weather data accumulated by the data logger is included in Appendix B on Tables B1 to B3. Site A data was only available from late August until late October due to a failure of the data logger.

4.2 TEMPERATURE

Average daily temperatures for Site A are plotted on Figure 4.1 for August to October 1985. Daily means reached zero in mid September and by late October remained below zero most days. During the period March to October inclusive, the highest temperature observed by the KLMC station was 29.0°C on July 1st.

4.3 PRECIPITATION

For the monitoring period June 1st to October 31st the total precipitation at Key Lake as monitored by KLMC was 310.1 mm with 284.8 mm being observed as rain.

The precipitation observed at Site A was very much smaller than at the KLMC station. This is attributed to lower rainfall at the site, to evaporation from the tipping bucket due to the heating coils, interception by and loss from the mesh cover screen and the inability of the gauge to capture and melt snowfall.

TABLE 4.1

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

CLIMATE DATA FROM KEY LAKE CLIMATOLOGICAL STATION AND SITE A

	March	April	May	June	July	August		September		October	
	KLMC	KLMC	KLMC	KLMC	KLMC	KLMC	Site A·	KLMC	Site A·	KLMC	Site A·
Mean Temperature (°C)	-18.4	-1.5	8.0	11.2	15.0	14.2	*	5.7	6.1	-1.4	-1.3
Maximum Temperature (°C)	9.0	10.5	26.5	26.0	29.0	28.5	18.0	21.6	20.5	12.0	13.0
Minimum Temperature (°C)	-30.0	-25.0	-5.0	-5.0	4.0	2.5	4.2	-8.5	-5.0	-14.0	-9.5
Total Rain (mm)	0	14.1	11.8	100	80.6	50.4	*	43.8	*	10.0	*
Total Snow (mm)	25.3	36.3	0	0.2	0	0	*	0.9	*	24.2	*
Total Precipitation (mm)	25.3	50.4	11.8	100.2	80.6	50.4	0.5	44.7	4.3	34.2	1.0
Days with Precipitation	12	13	9	19	15	17	1	11	3	10	1
Net Evaporation (mm)	*	*	114.7	173.3	213.6	155.5	*	113.6	*	5.1	*
Wind Run (km)	9700	10414	10315	9621	10947	9862	*	11840	*	11114	*
Average Speed (km/hr)	13	14.5	13.9	13.4	14.7	13.3	*	16.4	*	14.9	*
Maximum 24 hours (km)	544	958	764	573	579	756	*	718	*	634	*

* Data Not Collected

· Partial month only

KLMC Wind Run Gauge Elevation = 13 metres

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MONITORING OF LAYERED URANIUM TAILINGS
PHASE II
DATA SUMMARY
SITE A - ATMOSPHERIC TEMPERATURE

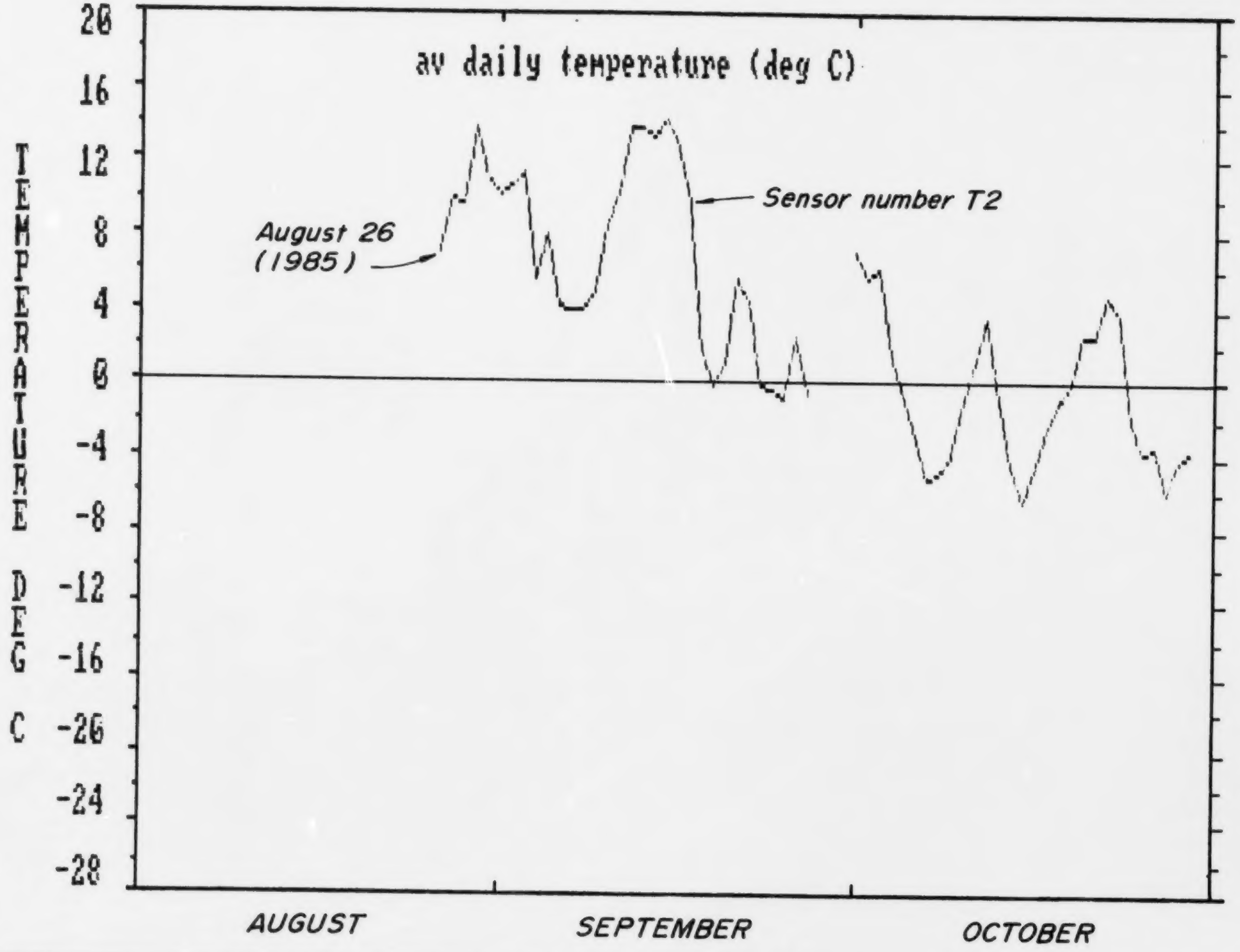

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FIGURE 4.1

4.4 WIND RUN

Wind run data was available from the KLMC station and is summarized on Table 4.1.

4.5 EVAPORATION

Pan evaporation as measured by KLMC is summarized on Table 4.1. For the period May 14th to October 3rd, 1985, the total net pan evaporation was 775.8 mm of water. Significant pan evaporation was observed at the commencement of evaporation monitoring which suggests that the above total is low. Examination of climatological data indicated daily temperatures were constantly above freezing beginning in late April. For future monitoring seasons the pan might be installed if possible in mid-April and monitored as best as possible under the prevailing conditions.

SECTION 5.0 - TAILINGS PHYSICAL DATA

5.1 SURFACE CONDITIONS

A general chronology of observations of tailings deposition, surface conditions and field work during this study is included on Table 5.1.

In summary, at the conclusion of Phase I in March 1985 approximately 2.0 metres of tailings were in place over both Site A and Site B with significant ice and snow depths. At the first site visit for the Phase II program in late May 1985, no ice or snow was visible in the facility, nor could any be located by probing adjacent to Site A or Site B. Tailings deposition was into the south half of the facility with on-going coverage of Site B. At Site A the total tailings depth was approximately 1800 mm. The tailings surface was dry, cracked and extremely porous to a depth of approximately 150 mm. The cracks extended to a depth of over 300 mm in many locations and were up to 50 mm in width. Foot traffic was easily accomplished leaving a full foot print impression. Jumping on the surface left a deeper impression but it was not possible to draw water to the surface. Excavation to install pressure sensors showed that the deeper tailings at Site A were saturated and not visibly porous.

Significant hummocking and heaving of the surface was apparent in the downstream half of the tailings facility. This coincided with regions where stored water had been standing or tailings were deposited during the previous winter and is attributed to frost heave. As discussed in the Phase I report, approximately 500,000 cubic metres of water had been temporarily stored in the facility during 1984 and had still not been completely removed by the end of 1985 (Photograph Nos. 3, 4 and 5).

During the monitoring period tailings deposition was predominantly on the south side of the facility covering Site B with a tailings depth in excess of 3

TABLE 5.1

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

VISUAL OBSERVATIONS OF TEST SITES

DATE	
March 11, 1985	- Phase I monitoring terminated - 2.0 metres tailings over Site A and Site B - Site B tailings frozen to estimated depth of 1 m. - Site A tailings frozen to estimated depth of 0.35 m. - Tailings deposition from centre of facility fanning out over south side. - Freezing atmospheric conditions throughout
May 31 - June 4, 1985	- Phase II monitoring commenced - No visible ice or snow in facility - Ponded water extended full width of east end of facility and over 15% of total surface area. - Tailings deposited over south half of facility filling low spots left by winter deposition. - Site B access prevented by fresh tailings - Site B tailings depth approximately 2.1 metres - Site B temperature sensors indicated no frozen material present. - Site A surface dry and cracked. Easy foot access. - Thawed tailings were very porous, dry and crumbly and of low density. - Site A temperature sensors indicated no frozen tailings. - Site A standpipes indicate no standing water - A small quantity of water pumped from drainage sump under Site A using hand selector. - Weather cool and overcast with light showers. - Installed data logger, pressure sensors and moisture blocks. - Tailings depth at Site A approximately 1.8 m.
July 11 - 15, 1985	- Variable weather, generally warm with some evening showers or rain. - Rain ponding on surface and running into fissures (North side and centre).

- Site B covered with 2.7 m of tailings. Surface soft. Access no longer possible.
- Tailings still being deposited in south quarter of facility.
- Site traversed in two east-west lines for tailings sample collection.
- Probing to 3 m depth during traverse revealed no ice.
- Standing water pond reduced significantly in size.
- Drying and fissuring of tailings had increased since previous visit.
- No standing water in Site A standpipes
- Site A drainage blanket sump pumped dry using hand pump control. Insufficient water to automatically activate.
- Data logger failed to retain data collected since previous visit.
- Bad connection in moisture-density probe
- Cores taken for moisture determination at Site A.

August 23 - 26, 1985

- Weather initially warm, dry and sunny with light breeze. Wet and windy on morning of 26th.
- Standing water pond confined to extreme NE corner of facility.
- Tailings deposition continues on south side with tailings running full length to sloping filter on east side.
- Site B covered with 3.0 m of tailings
- Surface cracking of tailings in SE corner of facility.
- Data logger returned to site and reinstalled
- Tailings surface "slick" after rain. More so than previous visit.
- Drying and cracking of older areas appeared to have reached maximum extent.
- Tailings previously under water are extremely variable in surface elevation with numerous ridges and valleys.

September 27 - 30, 1985

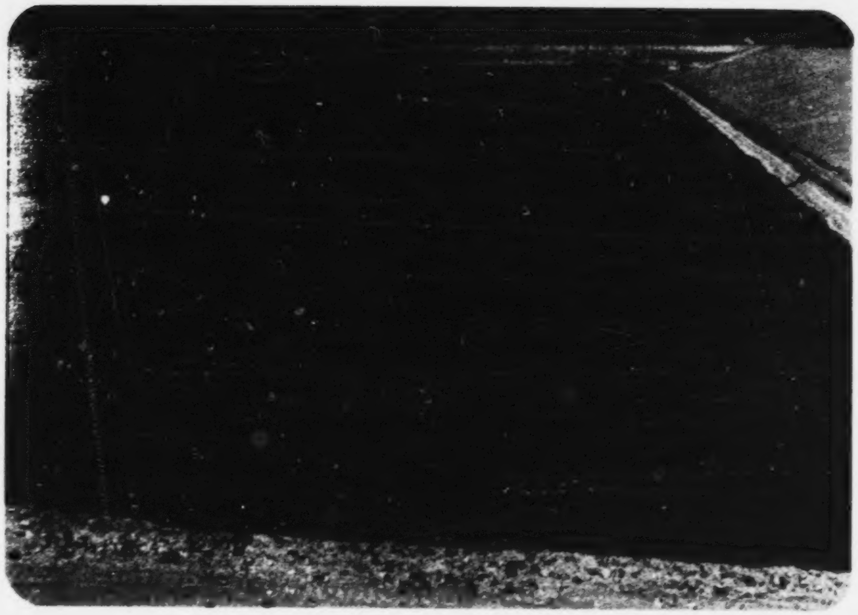
- Freezing conditions overnight with thawing during the day. Shaded areas remaining frozen. No snow.
- Spraybars have been raised to next bench on north side.
- Approximately 500 mm of fresh tailings were

deposited over test Site A from September 12 to September 24.

- Tailings over Site A have settled approximately 200 mm from the peak elevation as shown by mud lines on the standpipes.
- Steady discharge of underdrainage from Site A not affected by surface freezing and thawing.
- Limited access to Site A only when surface frozen.
- Water in Site A standpipes varied from 0.15 to 0.75 m, showing drawdown to collector drain.
- No surface runoff from fresh tailings while surface frozen.
- Runoff of clear water begins as frozen surface thaws.
- Surface water runoff reaches a maximum in early afternoon and falls to zero by late afternoon with surface appearing relatively dry. Surface freezes again overnight and runoff cycle repeated.
- Tailings are being discharged from low spots on south side. Limited remaining capacity on south side to lowest operating bench.
- Exposed and weathered tailings are "wetter" and slicker than observed during previous trips. Some apparent closing of cracks.
- Buried ice located immediately south of SE corner of temporary confinement embankment at a depth of approximately 600 mm. Extent not known.

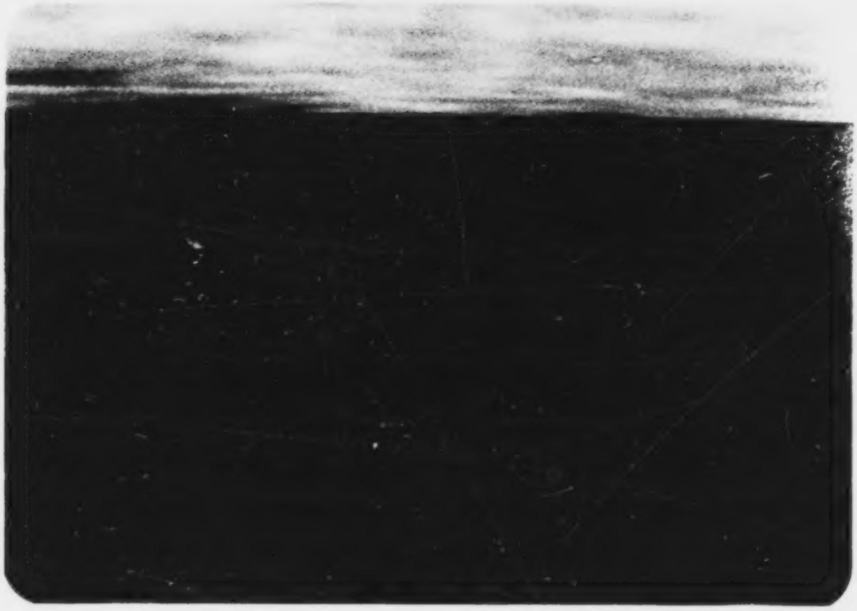
October 25 - 29, 1985

- Weather mostly freezing with some limited thawing in sunshine.
- Site A approximately 100 mm snow, 100 mm frozen tailings.
- Site B 200 mm snow.
- Tailings deposition from south side of centre of facility.
- South West corner mostly filled.
- Small flows continuing from Site A seepage blanket.
- Site A standpipes dry.
- Carried out laboratory tests on cylinders of fresh tailings to determine effect of freezing and thawing.
- Completed monitoring for Phase II programme.

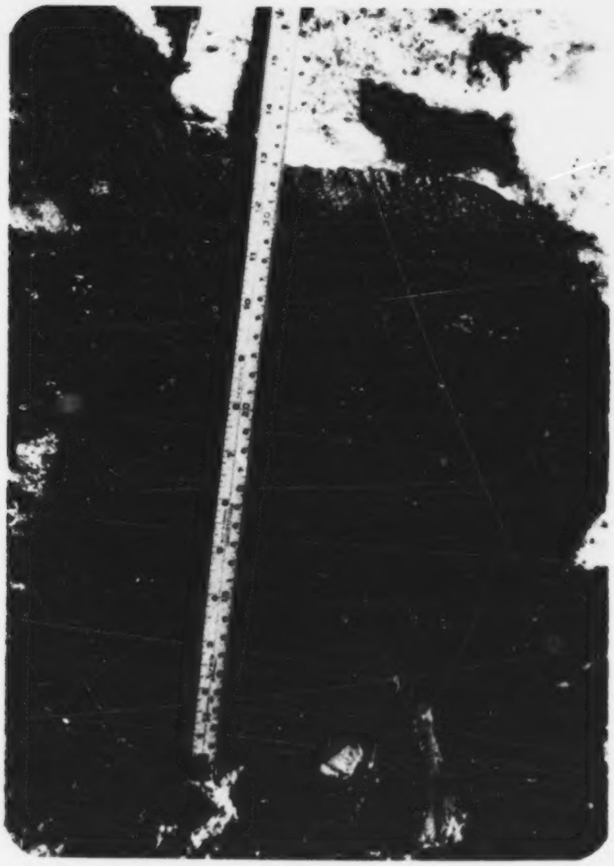


Photograph No. 3 View along east embankment at downstream end of facility, June, 1985. Fresh tailings in foreground, temporary water storage in background.

Photograph No. 4 Similar view to above showing significant water removal and consolidation of tailings adjacent to downstream embankment, July, 1985.



Photograph No. 5 Thawed tailings surface at downstream end of facility showing extensive hummocking 3 ft. to 4 ft. high. This area was previously covered with ice and winter tailings deposition.



Photograph No. 6 Frozen tailings material removed from Site A Winter 84/85 and partly thawed. Distinct layering, ice lenses and variable porosity are visible.

metres. Tailings were directed over Site A for two weeks only during mid September. Daily freeze-thaw cycles were observed on Site A during late September with significant runoff of clear supernatant. At the completion of Phase II in late October 1985, the frost penetration was approximately 100 mm at Site A, with variable snow cover over the entire facility.

5.2 PORE PRESSURE MONITORING

Variations in pore pressure transducer readings at Site A are included in Appendix B as Tables B4 to B6 and are summarized on Figures 5.1 to 5.3. The standpipes at Site A were dry at the termination of Phase I monitoring in March 1985, at the first Phase II site visit in May 1985 and all site visits except for late September, when readings were:

Standpipe	Tip Location	Water Surface Elevation (m)	Depth of Standing Water (mm)
SP1A	base of tailings	540.21	750
SP2A	base of tailings	539.66	150
SP3A	base of tailings	540.23	710
SP4A	base of tailings	540.27	660

This data indicates a strong drawdown of the phreatic surface to the Site A seepage drain which is located between SP1A and SP2A (Figure 3.2).

A subsequent observation made in late October 1986 showed that the standpipes were again dry.

Variations in atmospheric pressure are plotted on Figure 5.1. Data from this unit, which was sealed at sea level, was used as a reference to convert readings from the other sensors to readings at sea level. Other minor

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MONITORING OF LAYERED URANIUM TAILINGS
PHASE II

DATA SUMMARY
SITE I - ATMOSPHERIC PRESSURE VARIATION

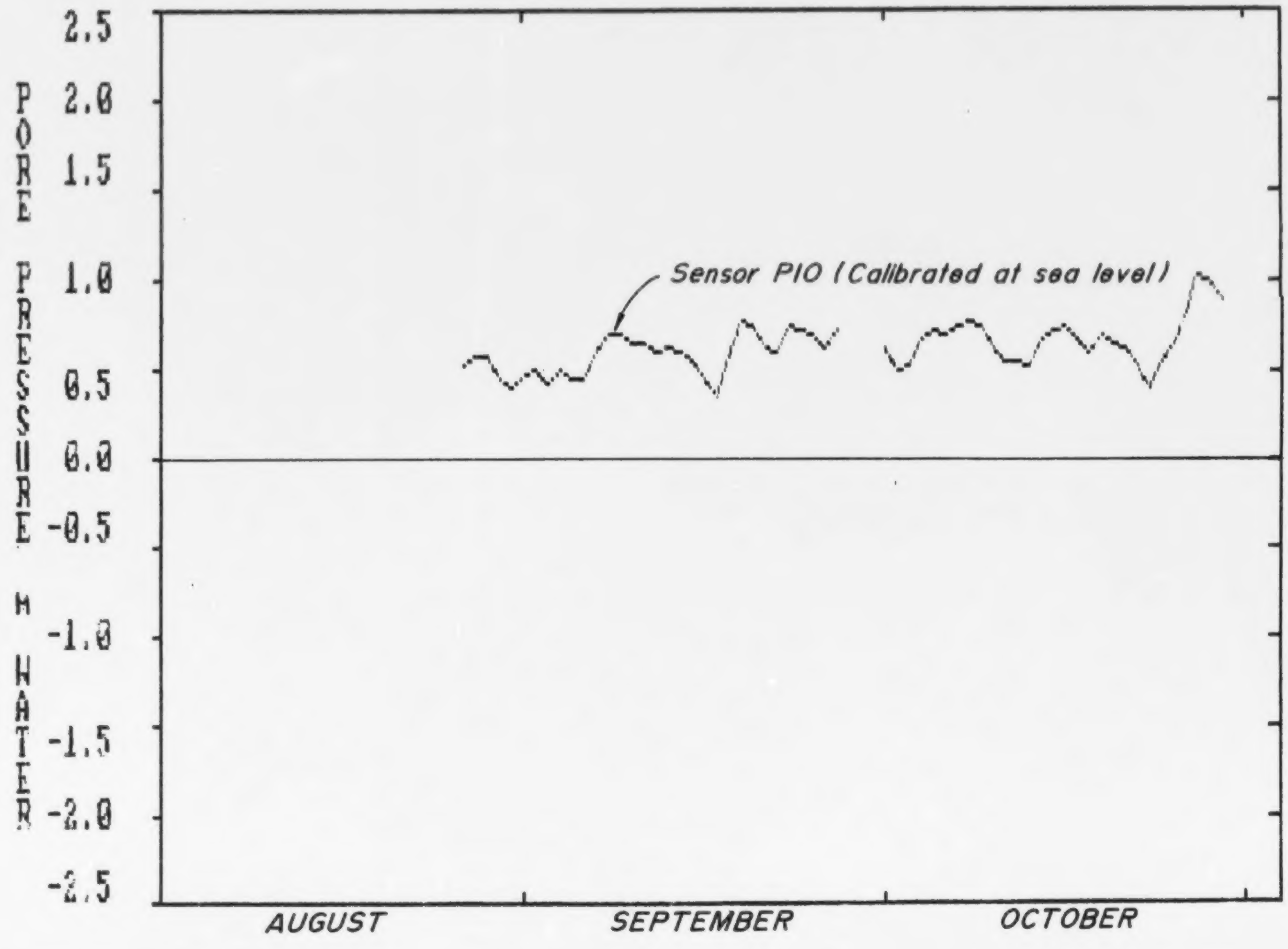

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FIGURE 5.1

MONITORING OF LAYERED URANIUM TAILINGS
PHASE II
DATA SUMMARY
SITE A - PORE PRESSURE IN TAILINGS MAST #P2

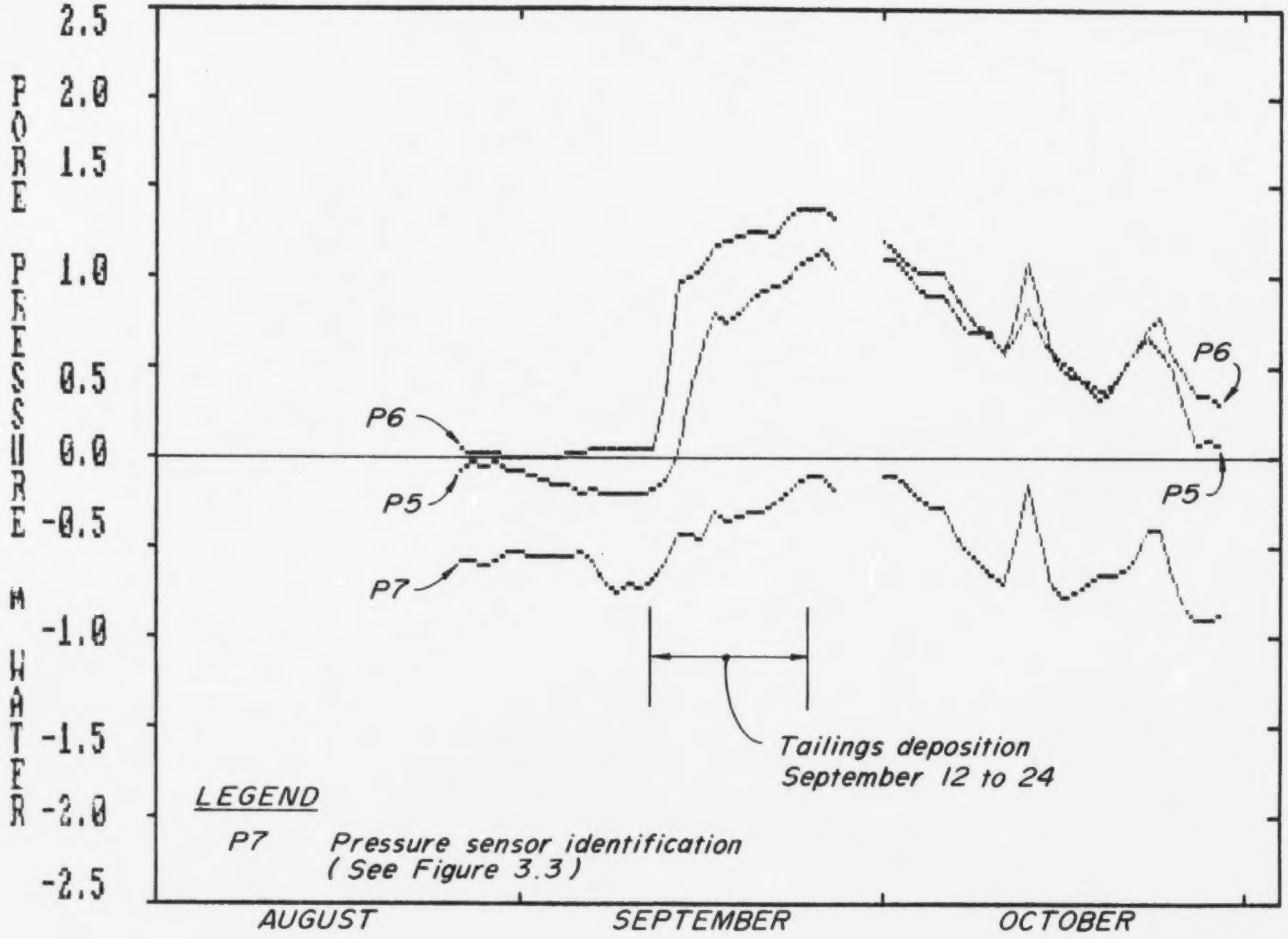

FIGURE 5.2

MONITORING OF LAYERED URANIUM TAILINGS

PHASE II

DATA SUMMARY

SITE A - PORE PRESSURE IN TAILINGS MAST #P1

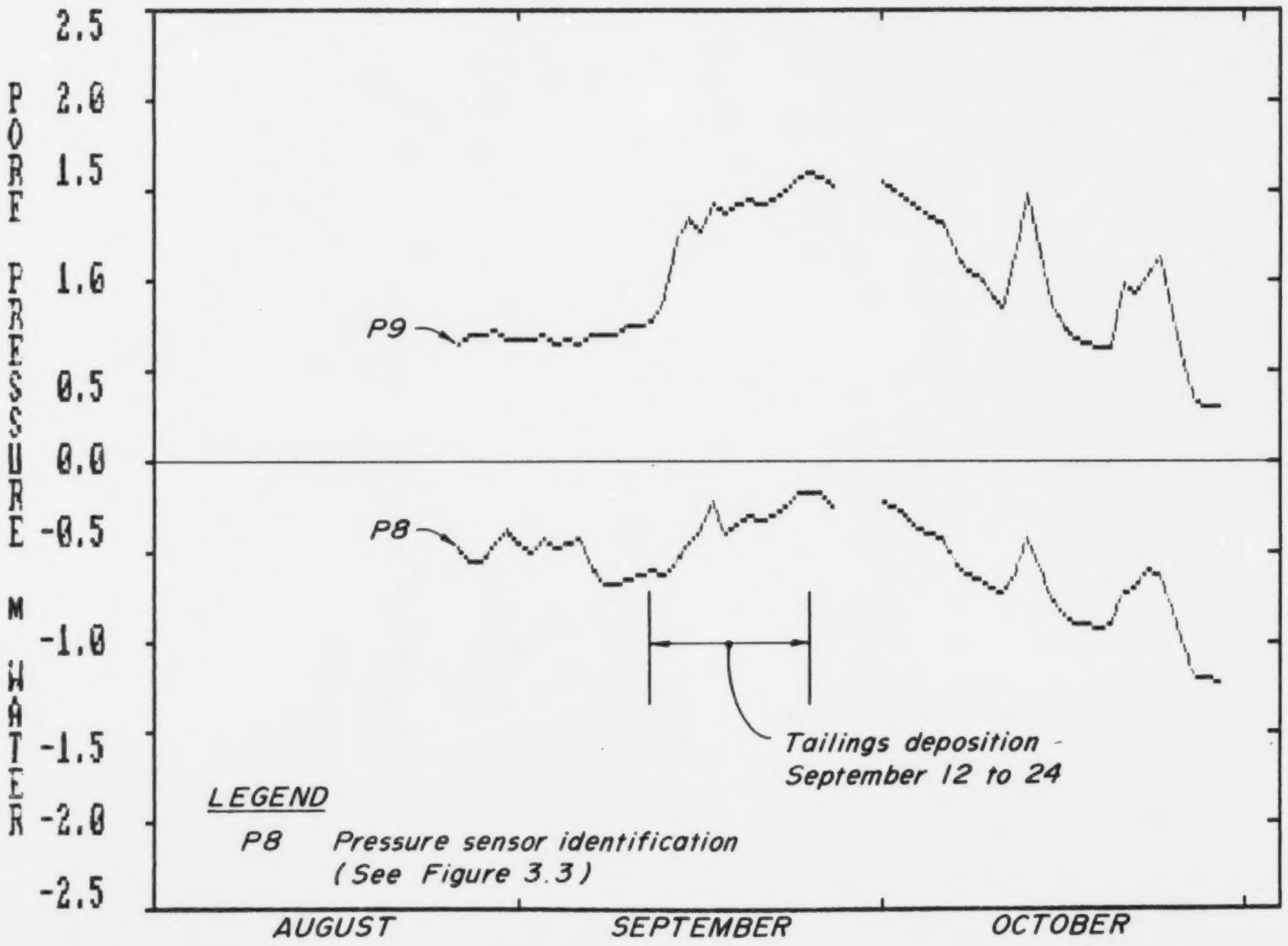

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FIGURE 5.3

corrections were included due to the different barometric pressures at the time each transducer was sealed.

Data available from the short period before the deposition of fresh tailings shows generally steady pressures with minor downward trends (Figures 5.2 and 5.3). More pronounced drops for P7 and P8 appear to be inversely related to pressure highs in the atmospheric monitor P10. It is possible that these two units were partially isolated from the effects of atmospheric pressure change perhaps due to air entrainment resulting from the long delay between their installation and deposition of fresh tailings over the test site.

With the deposition of fresh tailings over Site A pressure sensors P5, P6 and P9 showed pore pressure increases of up to 1.5 metres of water. Some increase is also observed in P7 and P8. The readings of these two sensors must be regarded with caution due to a possible lack of response of these units to the occurrence of a major atmospheric pressure low at this time.

The monitored pore pressures continued to increase slowly for all sensors for the duration of tailings deposition over the area.

Two major factors will probably have contributed to the increase.

(i) Resaturation of unsaturated tailings material.

(ii) A build-up of seepage water in the underlying and surrounding filter blanket.

Following relocation of tailings discharge away from the test site the pore pressures underwent a slow decline. Several short term peaks in October, closely correlate with atmospheric lows and with periods of thawing temperatures following several days of short term freezing temperatures.

An increase in seepage recovery also accompanies these peaks. The peaks are less pronounced for the more deeply buried sensors.

At the conclusion of monitoring the pore pressure in sensors P7, P8 and P9 were lower than they were prior to tailings deposition. Units P5 and P6, located closest to the seepage drain, indicated pressures above their pre-deposition values.

5.3 TEMPERATURE PROFILES, FROST PENETRATION AND THAWING

Temperature sensor locations and readings from within the tailings at Site A and Site B and from the atmosphere adjacent to Site A are plotted on Figures 5.4 to 5.7. Additional tabulated data is provided in Appendix B on Tables B1 to B6.

No field observations were made during most of March to June 1985 during which time the snow, ice and frost melted and the tailings surface dried.

Temperature data, summarized below for both sites indicates that thawing was complete by the time of the first site visit in early June 1985. This was confirmed by field observation and probing for ice at each test site (Photograph No. 6).

SITE A

Burial Depth of Temperature Probe in Tailings on March 10	Average Temperature March 10, 1985 (°C)	Average Temperature June 3, 1985 (°C)
1.9 m	4.5	5.4*
1.0 m	1.3	6.3*
0.1 m	-1.7	10.0 (approx)*

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MONITORING OF LAYERED URANIUM TAILINGS

PHASE II

BURIAL DEPTH OF TEMPERATURE SENSORS – SITE A AND SITE B

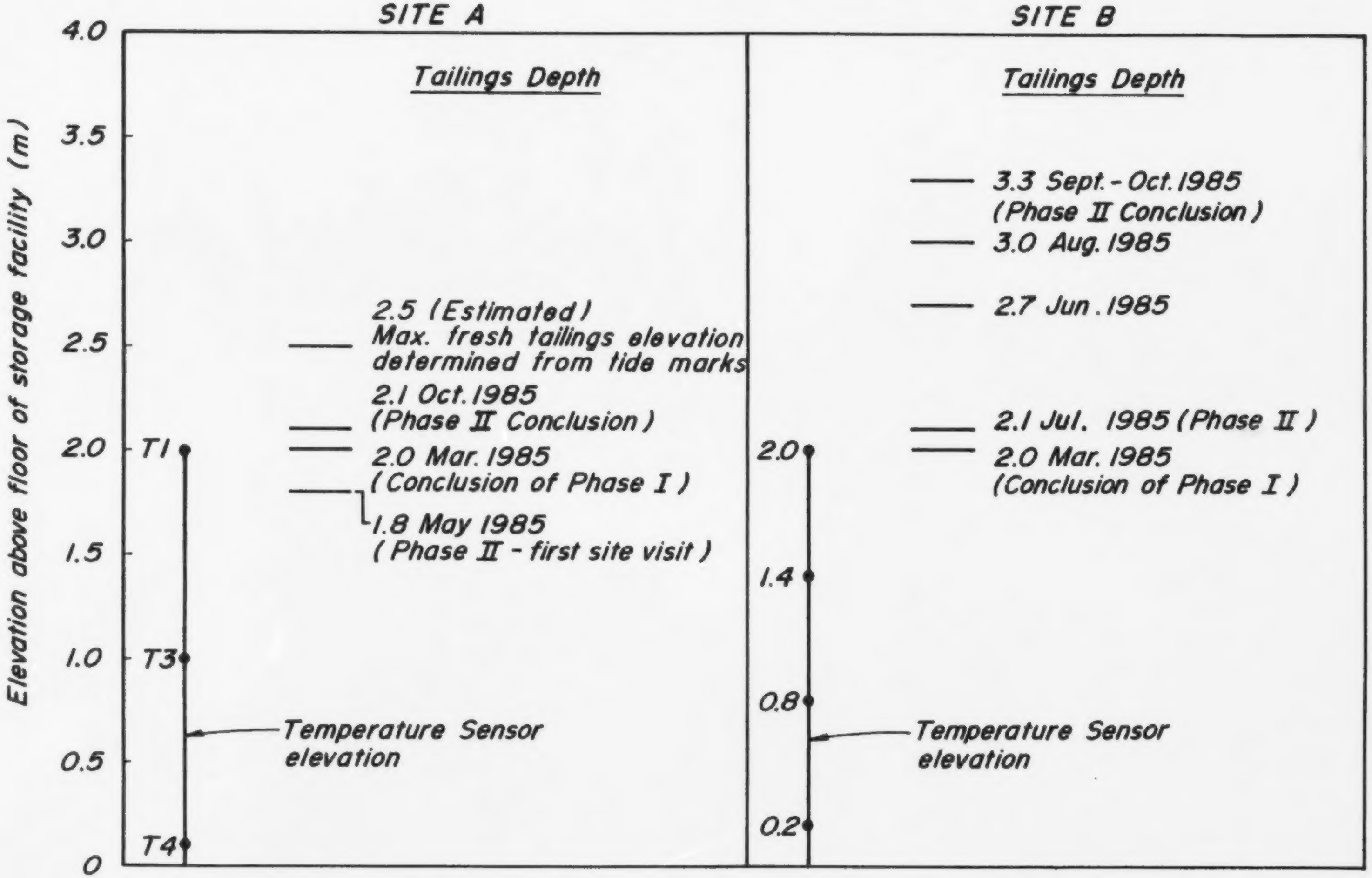

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FIGURE 5.4

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MONITORING OF LAYERED URANIUM TAILINGS
PHASE II

DATA SUMMARY
SITE A - TEMPERATURE IN TAILINGS

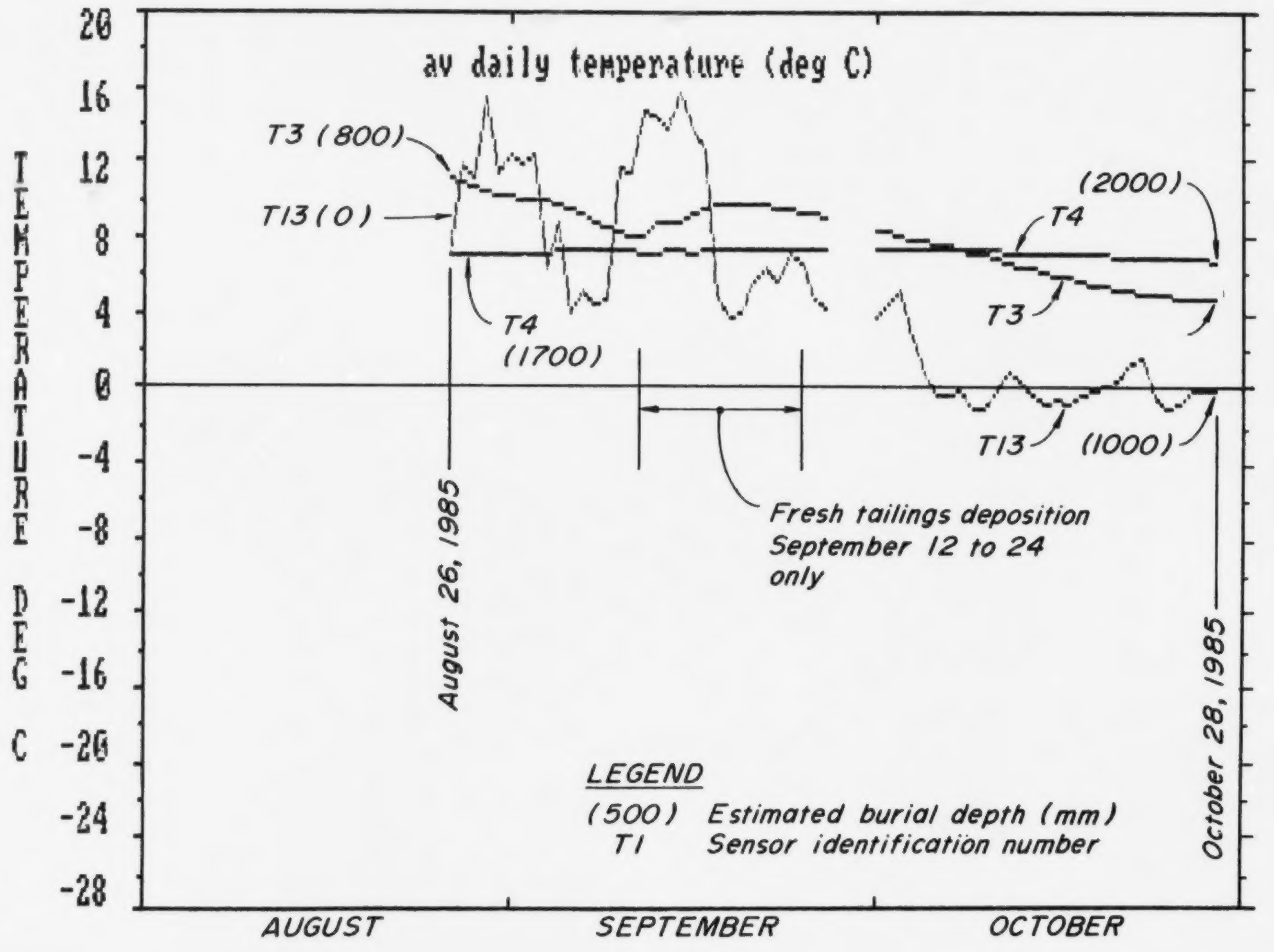

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FIGURE 5.5

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MONITORING OF LAYERED URANIUM TAILINGS
PHASE II

SITE B TEMPERATURE PROFILE

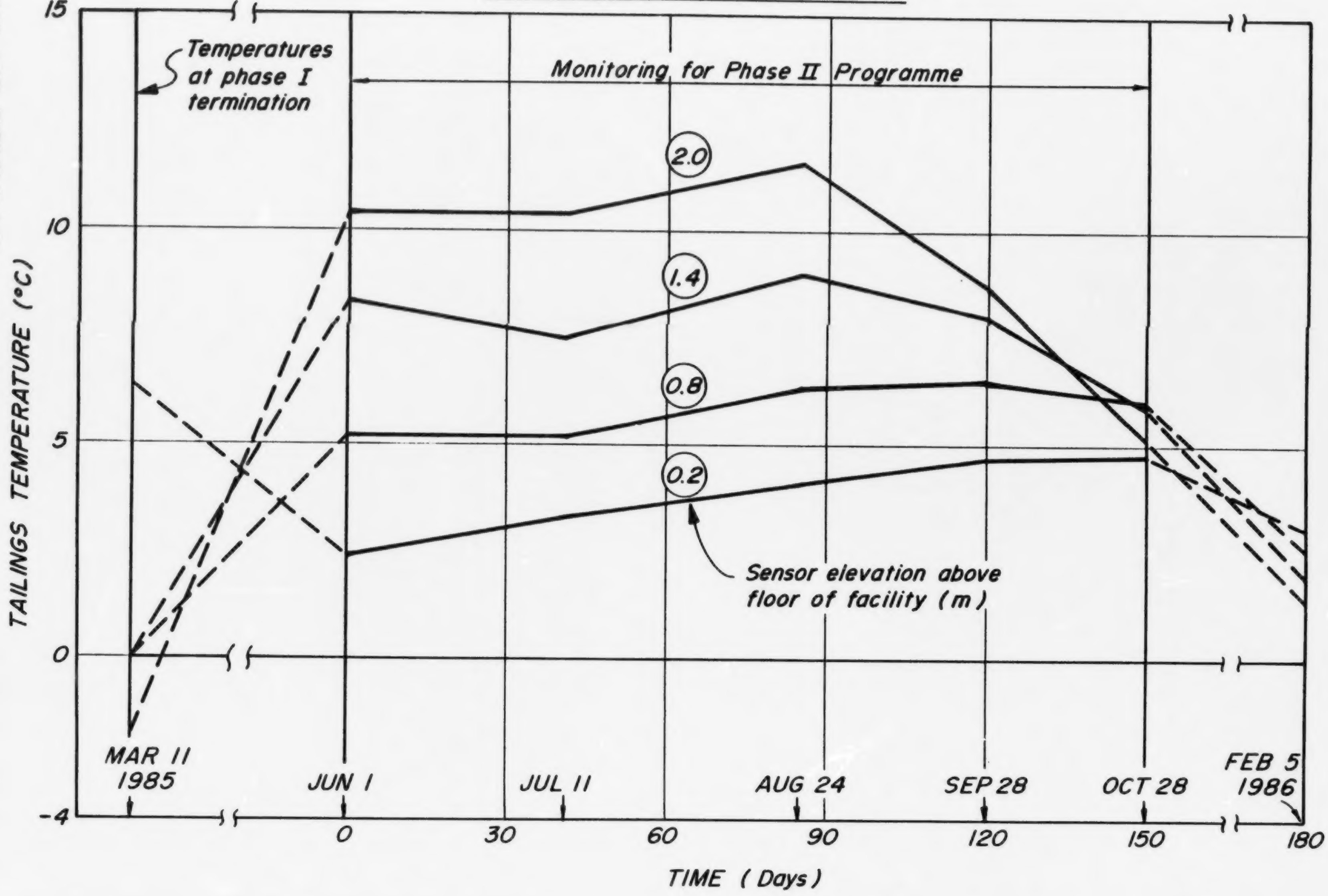

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FIGURE 5.6

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MONITORING OF LAYERED URANIUM TAILINGS

PHASE II

TYPICAL DIURNAL VARIATION OF TAILINGS AND AIR TEMPERATURES

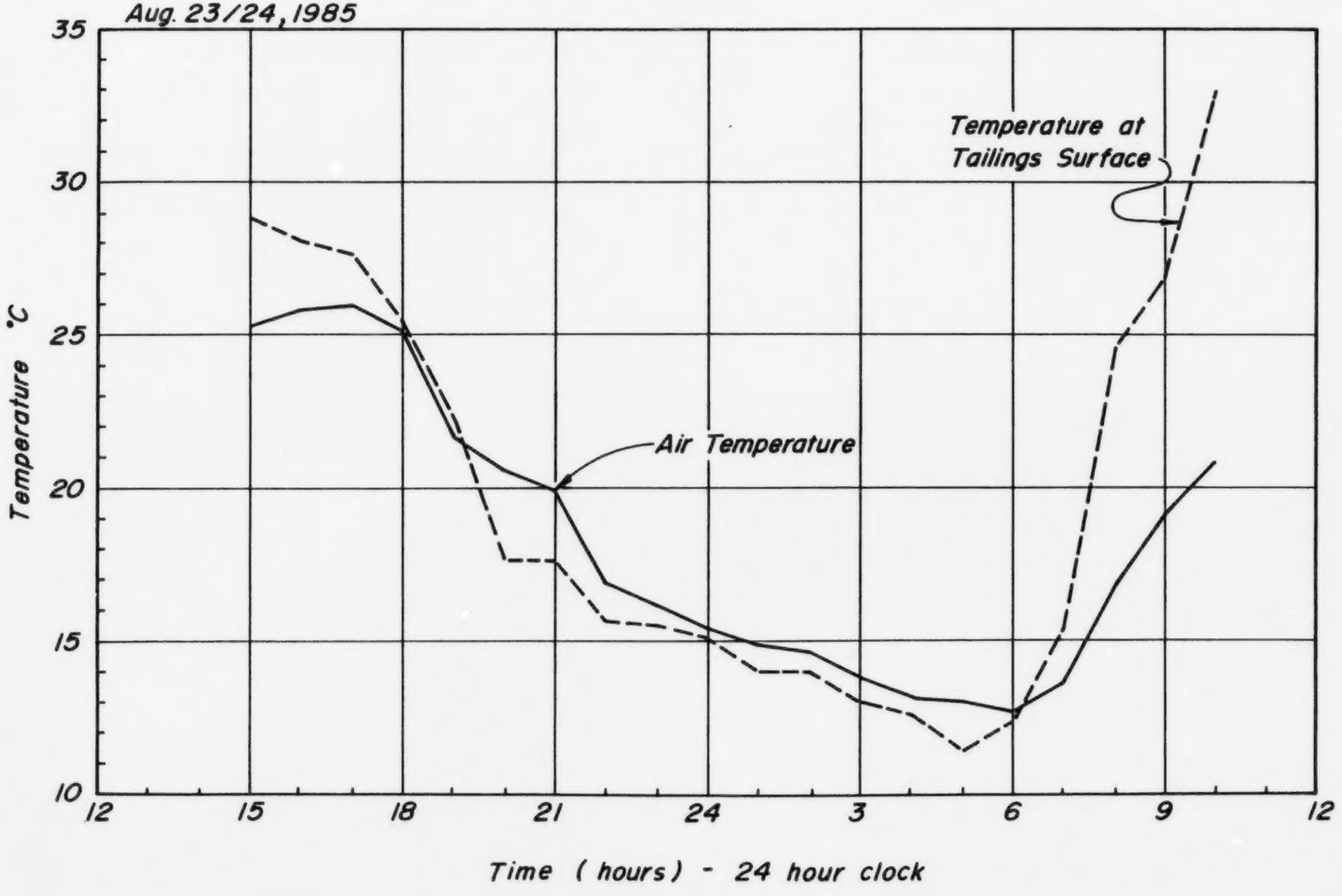

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FIGURE 5.7

SITE B

Burial Depth of Temperature Probe in Tailings on March 10	Average Temperature March 10, 1985 (°C)	Average Temperature June 3, 1985 (°C)
1.8 m	1.2	2.4
1.2 m	0.1	5.2
0.6 m	0.0	8.5
0.1 m	-1.2	10.9

* Data extracted manually from data logger and not reported elsewhere.

Data collected during Phase I indicated frost penetration in the facility to be approximately 1 metre.

Comparison of the air temperature and tailings surface temperature at Site A shows the average daily surface temperature to generally be higher than air temperatures during daylight hours (Figure 4.1, 5.5 and 5.7). This observation mostly holds true between early June and mid September during which time the tailings surface was extremely dry. Following the deposition of fresh tailings over Site A in mid September the surface temperature sensor was buried and less influenced by variations in atmospheric temperature. The influence of atmospheric temperature on other sensors decreased with the depth of burial. The sensor T4 located 0.1 m above the tailings floor varied between a low of 4.5°C at the conclusion of Phase I in early March and peaked at 7.3°C in early October, and decreased thereafter.

5.4 SEEPAGE QUANTITIES

Seepage quantities at Site A as determined from the data logger and from the flow meter are plotted on Figure 5.8.

No seepage data was recorded between the termination of Phase I monitoring in early March and the first site visit of Phase II in late May due to the severing of the main power cable to the monitoring hut. Some flow would have been expected from thawing or rain storm events. The flow meter had actually run backwards during this period. This was later observed to be due to convective air flow through the flow meter pipework when it was drained.

In late May, the pipework was refilled by manually starting the pump causing the convective air currents to stop. The system was again drained and further meter reversal occurred until the second site visit in July 1985 when the system was manually refilled and flushed prior to collecting a seepage sample.

Even though power was restored by late May 1985 no pumped flow occurred automatically until tailings deposition occurred during mid September 1985.

The only monitored rainfall of significance after the recommencement of data logging (3.5 mm on September 5, 1985) generated no detectable seepage.

Tailings were deposited over Site A (which has an area of 24 m^2) during the period September 12 to September 24 only. Seepage was detected within 24 hours, rising to a peak rate of 1.69 m^3/day. This corresponds to a seepage rate from the tailings of 8.2×10^{-7} $m^3/m^2/s$ and compares to the value of 5.9×10^{-7} $m^3/m^2/s$ observed during Phase I monitoring. Observation of mud lines on the exterior of standpipes in Site A indicate that the maximum depth of fresh tailings during deposition was not more than 0.7 metres. The fresh tailings surface had settled to a thickness of approximately 0.3

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PHASE II

DAILY PUMPED SEEPAGE (SITE A)

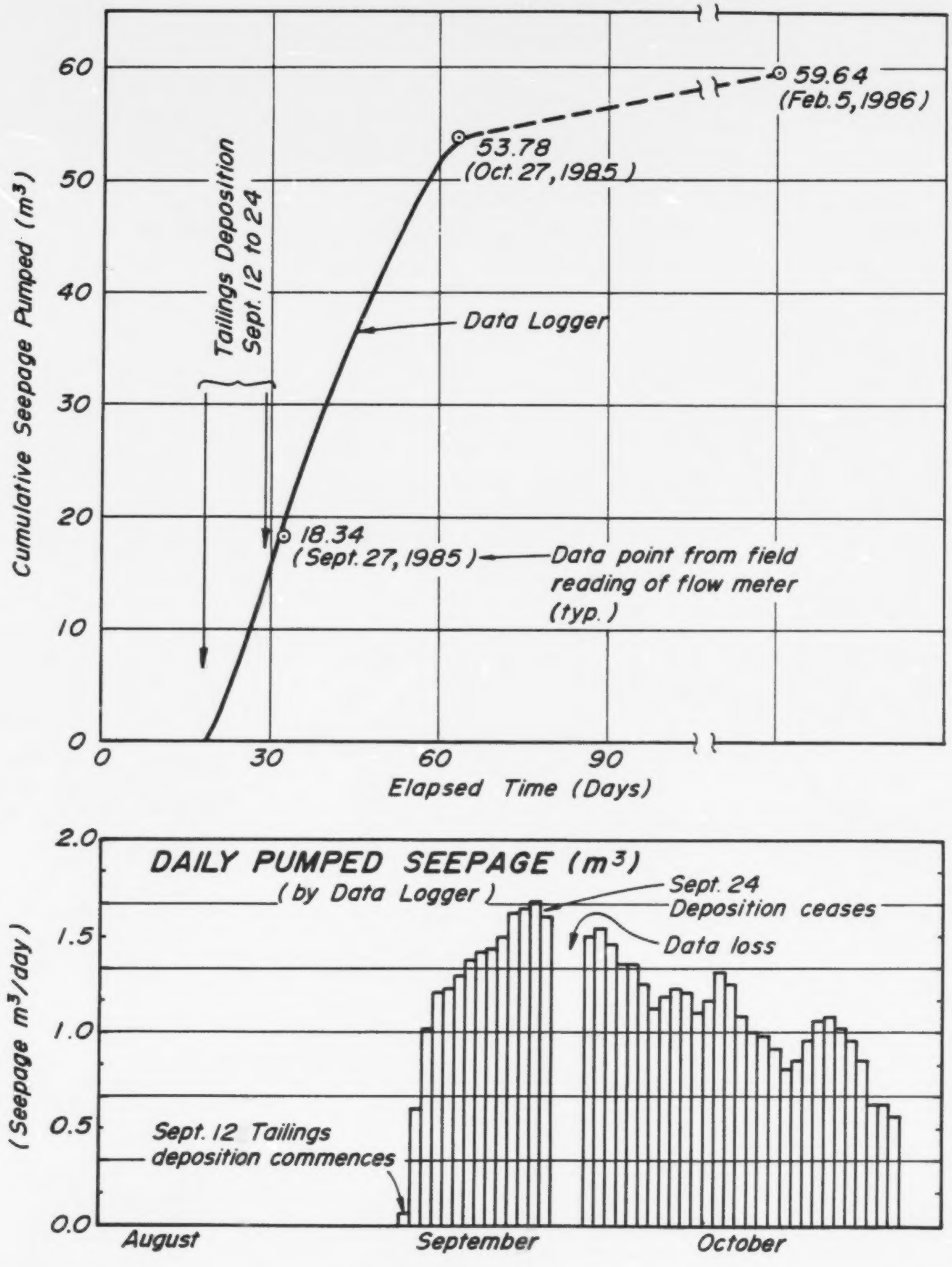

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FIGURE 5.8

metres, 6 weeks after deposition, at the termination of monitoring in late October.

The total seepage recovery had reached 16.1 cubic metres 24 hours after tailings deposition was terminated, with a steady decline thereafter. Several minor peaks in flow rate were observed during this decline. While not conclusive, these peaks indicate that some flow increase occurred when warmer temperatures followed a period of freezing temperatures. As reported below, water releases from the tailings have been observed to accompany daily freeze-thaw cycles. At the termination of Phase II, one month after tailings deposition had ceased, the daily flow was still approximately 30% of the peak flows and the total accumulated flow at the end of October was 53.8 m^3. At a site visit on February 5, 1986, the total seepage recovered had reached 59.6 m^3 or approximately 2.5 m^3 per square meter of the test site.

This total flow is several times greater than the expected water recovery from the estimated depth of tailings placed over the test site. As discussed in the Phase I report, Site A is located midway between drainage pipes in the filter blanket in an area of near flat grade. This can result in a significant head build-up in the filter blanket surrounding the test site as a result of drainage from fresh tailings and consequent inflow to the site from a much larger area. This is shown schematically on Figure 5.9. (Refer also to Figure 2.1 and Photograph No. 8).

5.5 EFFECTS OF FREEZE-THAW CYCLES ON KEY LAKE TAILINGS

5.5.1 Introduction

During a site visit in late September 1985 freshly deposited tailings at Site A were observed to freeze over-night at the surface. Under warming conditions the following day, thawing occurred with the

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MONITORING OF LAYERED URANIUM TAILINGS

PHASE II

INFLOW OF SEEPAGE TO TEST SITE A COLLECTOR DRAIN

(NTS)

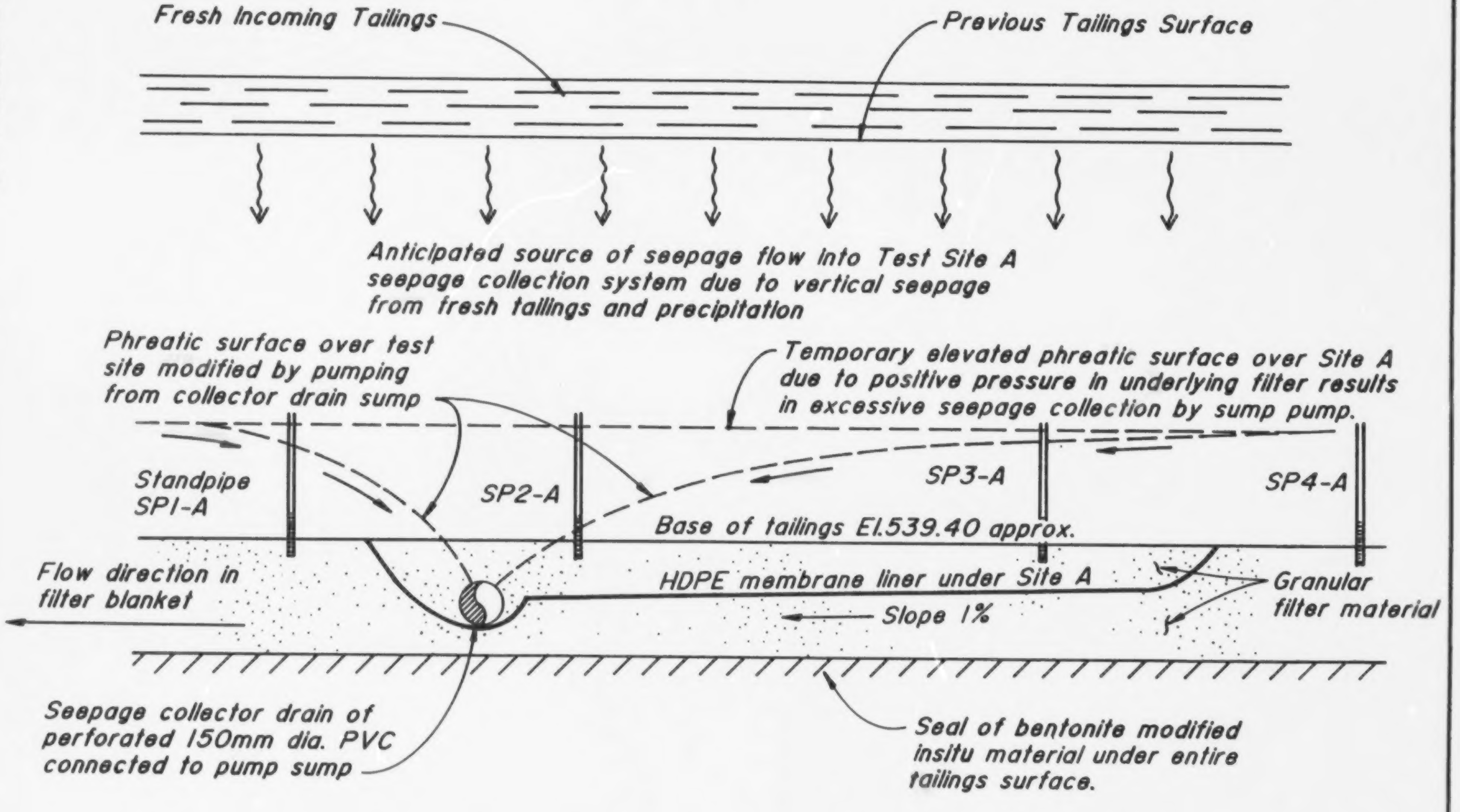
Fresh Incoming Tailings
Previous Tailings Surface
Anticipated source of seepage flow into Test Site A seepage collection system due to vertical seepage from fresh tailings and precipitation
Phreatic surface over test site modified by pumping from collector drain sump
Temporary elevated phreatic surface over Site A due to positive pressure in underlying filter results in excessive seepage collection by sump pump.
Standpipe SP1-A
SP2-A
SP3-A
SP4-A
Base of tailings El.539.40 approx.
Flow direction in filter blanket
HDPE membrane liner under Site A
Slope 1%
Granular filter material
Seepage collector drain of perforated 150mm dia. PVC connected to pump sump
Seal of bentonite modified insitu material under entire tailings surface.

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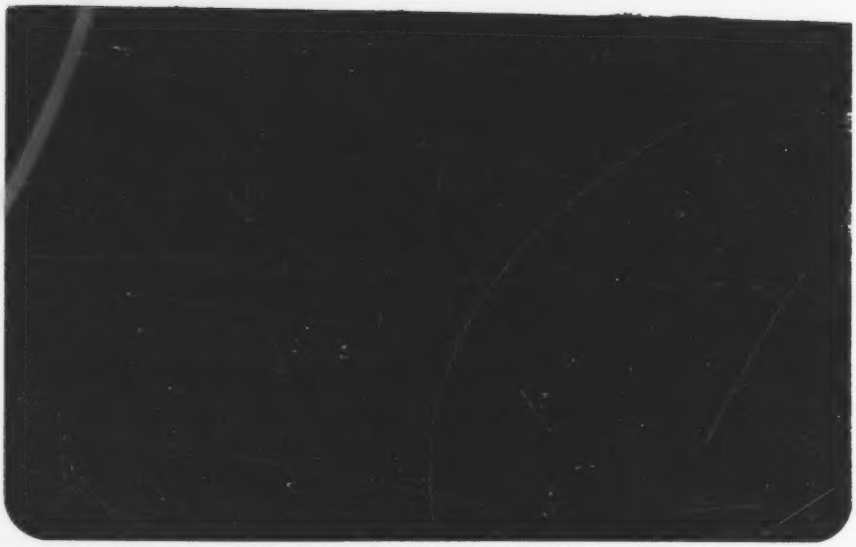
FIGURE 5.9

Photograph No. 7 Frozen surface of fresh tailings over monitoring site. Sun rise Sept 1985. No visible surface runoff.



Photograph No. 8 Thawed tailings surface at mid morning looking downstream to monitoring site. Abundant clear water runoff. Dry areas astride monitoring site are located over filter blanket drains.

release and runoff of significant quantities of clear supernatant. (Photograph Nos. 6 and 7.)

Other observations within the facility showed that tailings which had thawed after a winter freeze were extremely dry and porous in structure. In addition, many areas of the tailings facility showed topographic features characteristic of soils strongly influenced by freeze-thaw cycles.

As a result of these observations a small laboratory test programme was carried out in October 1985 at the Key Lake site to investigate the effects of freezing and thawing on the tailings. This work is described in Section 5.5.3.

5.5.2 Freeze-Thaw Behaviour in Soils

It has often been observed that freezing and thawing changes the engineering properties of soil. Various researchers have found that soil freezing results in ice segregation and causes changes in soil structure and permeability. A general description of some of the mechanisms and effects of freeze-thaw processes in soils are summarized in this sub-section. A more comprehensive treatment of this subject is provided by; Chamberlain and Blouin (1978), Chamberlain and Gow (1978) and Chamberlain (1981).

Freezing of a saturated soil often results in the formation of discrete ice lenses which are visually free of soil particles. Water is drawn to the ice lenses by suction forces generated by the freezing process. These suction forces cause an increase in the effective stress and subsequent consolidation of fine grained materials. The size and spacing of the ice lenses depends on the permeability of the soil and is related to the grain size characteristics of the material.

In sands, ice lens formation is limited by the maximum suction pressures that can be sustained in the relatively large soil pores. Freezing of saturated silts can result in a significant thickness of ice with associated surface frost heaving as water is readily drawn to the ice surface. In fine grained clayey materials, ice lenses are typically smaller and more closely spaced, since the lower soil permeability restricts moisture movement. Also, the clay material consolidates under the increased effective stresses caused by the suction gradients, so that frost heaving is less significant.

The distribution of ice in a freezing soil also depends on the direction of freezing. For a flat lying, fine grained homogeneous clayey material, vertical cracks will develop in a polygonal pattern, similar to dessication cracking. Horizontal ice lenses will also develop. In silts, pore fluids may more readily migrate and thicker horizontal ice lenses develop, but little cracking within the soil mass will be noted, since the silt skeleton is relatively incompressible.

The permeability of the soil to water is also increased substantially by freeze-thaw processes. Numerous preferred pathways for seepage develop due to ice lens formation or consolidation of fine grained clay materials within the pore spaces of the incompressible silt skeleton.

The implication for Key Lake tailings is that a freeze-thawed layer will drain more readily. However, it is also anticipated that subsequent tailings streams may plug some of these preferred pathways with fine grained silt and clay materials, thus reducing the vertical migration of tailings fluids through the deposit. The skeletal structure is also subject to collapse and consolidation with further loading.

Air drying of thawed tailings will result in a substantial reduction in drying shrinkage when compared to fresh unfrozen tailings. This is because the soil mass has already been consolidated extensively and drying removes excess water contained in voids which were previously filled with ice. Therefore, the bulk density of the tailings may be low as numerous large voids will be present in the thawed and drained material. These soils may prove to be highly compressible depending on the degree of ice formation. Also, saturated soils will consolidate much more rapidly after thawing, since the soil permeability will have increased substantially.

References

1. Chamberlain, E.J. (1981).
   Over-consolidation effects of ground freezing. Engineering Geology, 18, pp. 97-110.

2. Chamberlain, E.J. and Blouin, S.E. (1978).
   Densification by freezing and thawing of fine material dredged from waterways. Proc. 3rd International Conference Permafrost, Edmonton, Alberta, pp. 623-628.

3. Chamberlain, E.J. and Gow, A.J. (1978).
   Eflect of freezing and thawing on the permeability and structure of soils. Engineering Geology, 13, pp. 73-92.

5.5.3 Freeze-Thaw Tests on Fresh Tailings

This section describes laboratory test work carried out at the Key Lake site in late October 1985.

A quantity of fresh Key Lake tailings was obtained from the tailings discharge pump inlet in the bulk neutralization facility. The slurry solids content, determined by drying at 105°C, was 25.2% of the total weight, and the initial pH was 11.9.

The slurry was well mixed and a measured volume was placed in a series of 1000 ml plastic measuring cylinders. The test conditions for each cyclinder are outlined below:

Cylinder	Description
c	Settled at room temperature for 48 hours and then supernatant decanted and measured. Frozen outdoors overnight. Thawed and resettled without disturbance at room temperature. Additional quantity of supernatant measured.
d	Settled at room temperature for 48 hours. Supernatant not decanted. Frozen outdoors overnight. Thawed and resettled without disturbance at room temperature. Supernatant quantity measured.
e	Settled at room temperature for 48 hours. Supernatant not decanted. Frozen outdoors overnight. Thawed at room temperature. Remixed. Settled. Supernatant quantity measured.
f	Settled indoors for 72 hours without disturbance or freezing. Settling control. Supernatant quantity then measured.
g	Fresh tailings slurry immediately placed outdoors and settled briefly while freezing. Thawed and settled

	indoors without disturbance for 48 hours. Supernatant quantity then measured.
h	Fresh tailings slurry immediately placed outdoors and settled briefly while freezing. Thawed and settled indoors without disturbance for 48 hours. Superantant quantity then measured. (Duplicate of (g)).
i	Fresh tailings slurry immediately placed outdoors and settled briefly while freezing. Thawed indoors and then remixed. Settled for 48 hours and supernatant quantity then measured.
j	Drained and settled indoors for 24 hours. All seepage and supernatant removed. Frozen outdoors overnight. Thawed indoors. Redrained and additional seepage removed. Weighed to determine total water loss.
k	Drained and settled indoors for 24 hours. All seepage and supernatant removed. Frozen outdoors overnight. Thawed indoors. Redrained and additional seepage removed. Frozen outdoors overnight. Thawed indoors. Redrained and additional seepage removed. Weighed to determine total water loss.
l	Control for drained and settled test. Drained and settled indoors for 60 hours without freezing. Seepage and supernatant continually removed. Weighed to determine total water loss.

Notes:

1. To achieve freezing the cylinders were covered and placed outdoors overnight in sub-zero temperatures. For cylinders g, h, and i freezing conditions were not ideal and the entire contents were not frozen.

2. For j, k and l drainage was achieved through a small hole in the cylinder base. This was covered by a filter paper prior to placing slurry in the cylinder. Seepage was continually removed. For j and k any standing surface water was decanted prior to freezing.

3. Controls f and l indicate the time required for settling and for drained settling of the tailings to be completed and the water recovery and dry solids density that might normally be achieved by each procedure without freezing.

4. Samples of tailings decant water for analysis were obtained by filtering fresh tailings, by freezing fresh tailings and removing supernatant as the tailings thawed and by removing supernatant from thawed tailings that had been settled and decanted prior to freezing.

Results and Observations

The measured results for total water recovery (supernatant only for undrained tests; supernatant and drainage for drained tests) are included on Figure 5.10. The calculated dry densities obtained (weight of solids in the settled slurry volume) are included on Figure 5.11.

The water recovery and the density were significantly improved by freezing when compared to unfrozen controls. These results are summarized in Table 5.2 as well as on Figures 5.10 and 5.11 and Photograph No. 10.

The pH of the supernatant was 11.7 for a slurry that had been settled for 48 hours and then frozen and thawed without any remixing. It was 12.0 for a fresh tailings slurry that had been frozen and then thawed without any remixing.

Frozen slurries exhibited a tissue-like structure with thin parallel plates of solids and clear ice spiralling around the cylinder.

On thawing under water the solid tissue-like structures collapsed, with debris falling in a random pattern and building up an observeably different type of porous structure. The supernatant and entrapped pore water remained clear.

Thawing of drained tailings resulted in some debris fall but the initial solids structure remained largely intact. Drainage was also clear.

Porous structures similar to the above have been observed in the field and typical examples are shown in Photograph Nos. 11 and 12.

5.5.4 Decant Water Chemistry

The results of porewater analysis for tailings subjected to freeze-thaw cycles, and fresh tailings are summarized below:

TABLE 5.2

KEY LAKE PROJECT

MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

RESULTS OF FREEZE THAW TESTS ON SETTLED AND DRAINED SLURRIES

Cylinder		Test Sequence (Section 5.5.3)	Supernatant Collected (% of Initial Slurry Volume)	Calculated Dry Density of Solids (t/m^3)	Water Recovery (% of Initial Water in Sample)	Solids Moisture Content (%)
Initial Slurry		As Received	0	0.30	0	297
f*	(S)	Settle (Control)	14	0.34	15	258
c	(S)	Settle, Decant, Freeze, Settle	34	0.45	38	184
d	(S)	Settle, Freeze, Settle	35	0.46	39	181
e	(S)	Settle, Freeze, Remix, Settle	21	0.38	24	227
g	(S)	Freeze, Settle	20	0.37	22	231
h	(S)	Freeze, Settle	18	0.36	20	237
i	(S)	Freeze, Remix, Settle	14	0.35	16	251
l*	(D)	Drain and Settle (Control)	NC	0.48	42	172
j	(D)	Drain and Settle, Freeze, Drain and Settle	NC	0.62	58	126
k	(D)	Drain and Settle, Freeze, Drain and Settle, Freeze, Drain and Settle	NC	0.70	67	97

(S) Settled only without underdrainage
(D) Settled with simultaneous underdrainage
NC Not collected
* Control

Notes:

1. Each cylinder initially filled with a known volume of slurry containing 25.2% solids by weight.
2. Supernatant was collected for settled tests only and is the total of supernatant volumes decanted or observed.
3. Dry density = dry weight of solids/final volume of slurry (assumed to be saturated).
4. Water recovery = supernatant collected (undrained settling tests).
   = total weight loss (drained and settled tests).
5. Solids moisture content = weight of residual water/weight of solids.
6. Final slurry volume was estimated for cylinders c and d due to uneven solids settling in the cylinders.

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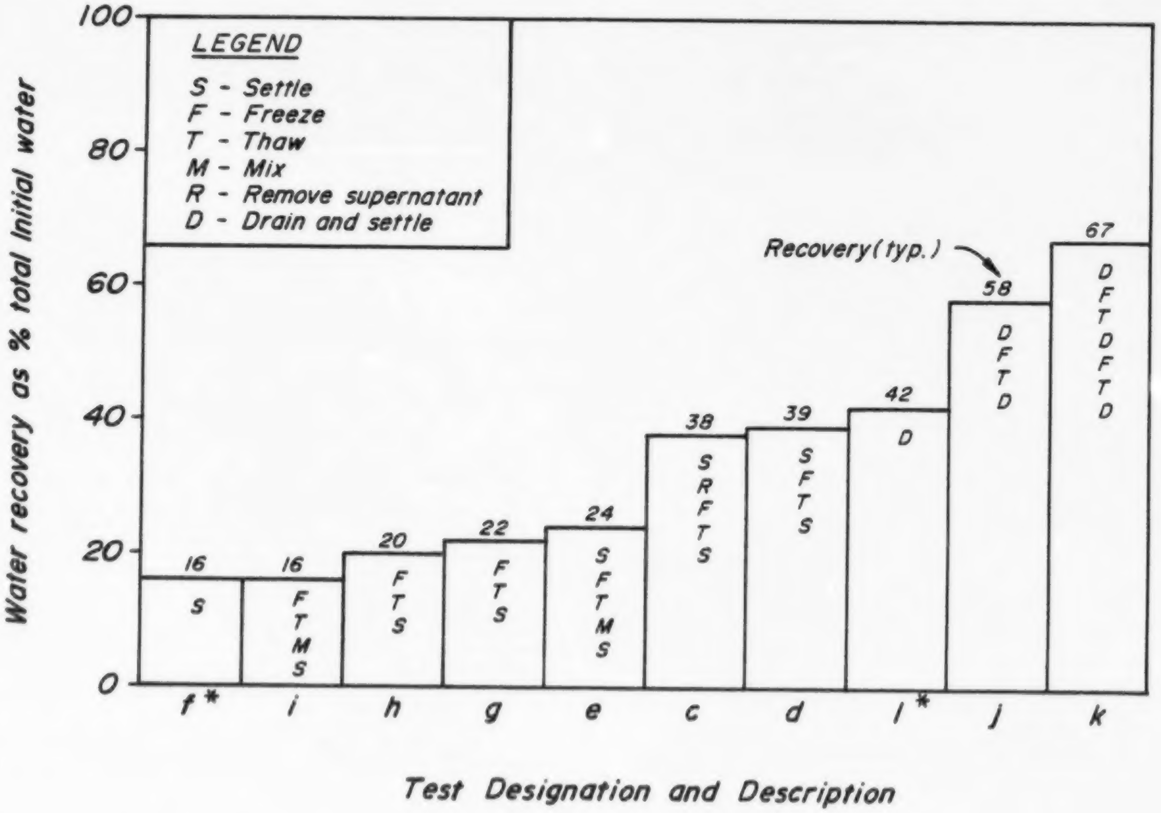
FREEZE THAW-TESTS-WATER RECOVERY FROM INITIAL SLURRY



* Control (Test carried out at room temperature)

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FIGURE 5.10

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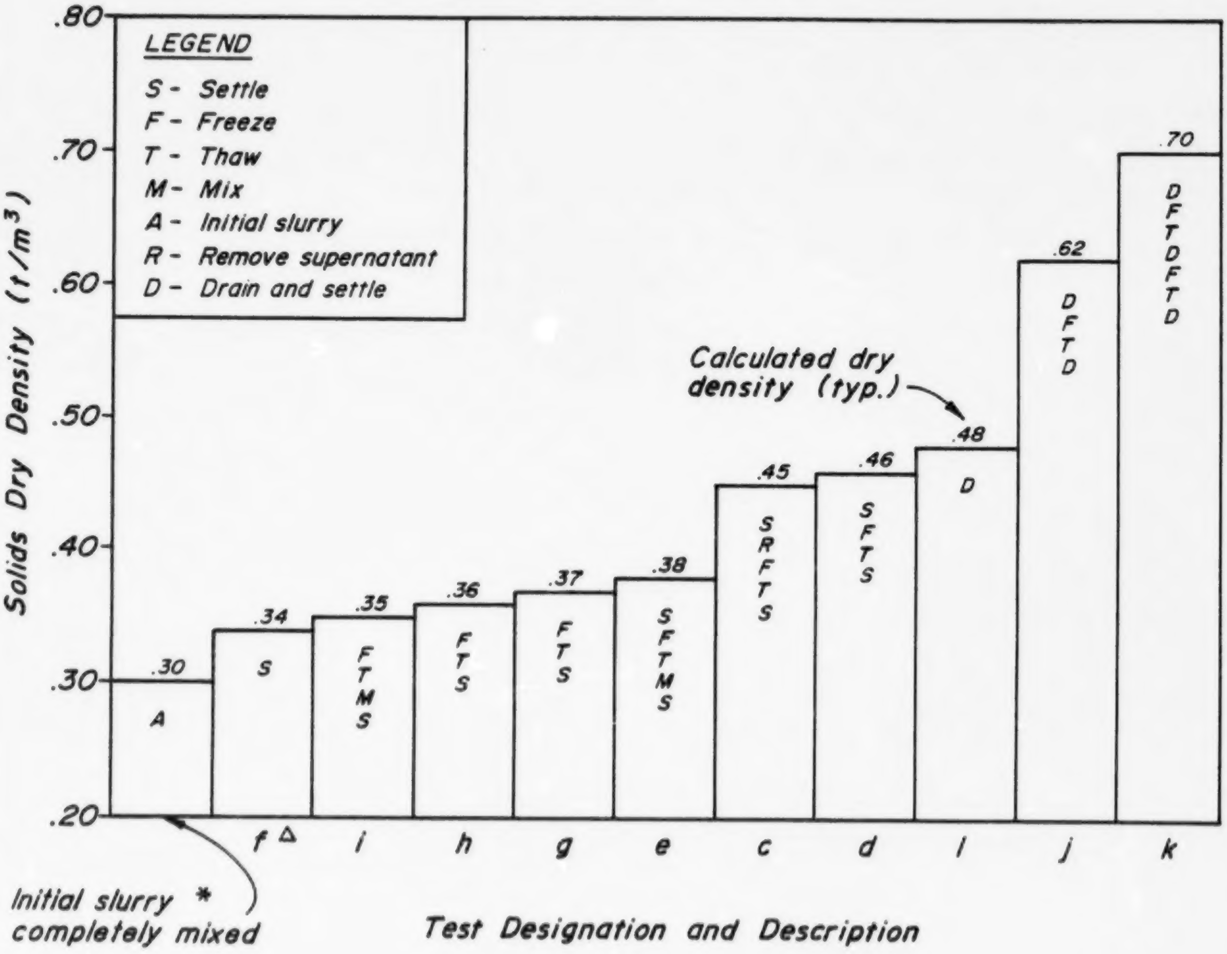
FREEZE-THAW TESTS - SOLIDS DRY DENSITY ACHIEVED



* All tests began with an initial slurry containing 25.2% solids by weight and a calculated dry density of 0.3 t/m^3

△ Control (Test carried out at room temperature)

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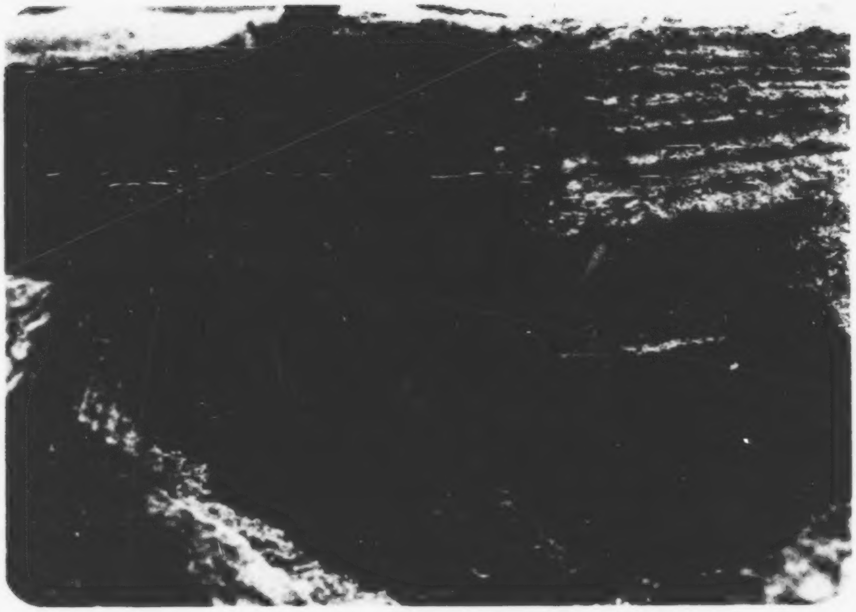
FIGURE 5.11

Photograph No. 9 Fresh tailings frozen overnight with clear ice overtop shows polygonal shrinkage cracking typical of fine grained material.

Photograph No. 10 Typical volume reductions in laboratory tests. RHS cylinder shows settling underwater. Centre shows added tailings consolidation with underdrainage. LHS shows further consolidation after freezing, with thawing and drainage still underway.



Photograph No. 11 *Well weathered tailings, subjected to freezing during winter 1984/1985 and subsequent thawing with free drainage. Layering and porous structure visible.*

Photograph No. 12 *Typical sample of fine grained tailing material subjected to a winter freeze-thaw cycle showing resulting open structure.*

Sample	Parameter				
	pH	As (ppb)	Ni (ppb)	Ra-226 (Bq/l)	Sulphate (mg/l)
Supernatant from fresh settled tailings.	11.8	140	2	308	1390
Supernatant from fresh tailings after freezing, thawing and settling.	11.6	750	4	211	1120
Supernatant from fresh tailings after settling, decanting, freezing, thawing then settling.	11.0	490	6	217	1190
Average of pore water from 8 cores (Table 8.1)	7.4/10.9*	5245	288	97.3	1625

* Refers to high and low values.

The analytical data falls within the broad range established during the Phase I monitoring for incoming tailings and surface runoff. Values for nickel, arsenic and sulphate are toward the low end of the range and they are significantly lower than the porewater analyses reported in Table 8.1 for cores extracted during Phase II.

Freezing appears to have resulted in some removal of sulphate and radium from solution and increases in arsenic and nickel.

5.5.5 Microscopic Examination of Frozen and Non-Frozen Tailings Samples

Samples of frozen and non-frozen tailings material were subjected to scanning electron microscope examination at Saskatchewan Research Council. Results are reported in Appendix D, which also includes several comparative photomicrographs, and are also summarized below:

A cursory examination of the two tailings samples showed that the sample that had been frozen had a lower moisture content (drier in appearance), was more consolidated (less plastic to the touch), and produced far fewer desiccation cracks when small thin samples were dried out at room temperature.

Two mechanisms were postulated by Saskatchewan Research Centre that might account for the different physical properties of the two samples.

(i) The first possibility involves improving particle packing, and the resultant increase in bulk density through the mechanical process of expansion and contraction induced by freeze-thaw cycling. (The role of this mechanism is likely minimal as the test material was subjected to a single freeze-thaw cycle).

(ii) A second mechanism involves the effect that freezing has on the behaviour of clay minerals. It has been observed that freezing slurries with a substantial clay content tends to flocculate the clays, the clay minerals agglomerate, thereby forming larger particles and release trapped/adsorbed water to the pore fluid.

The pore water then freezes and drains away after thawing, given the opportunity. The pore water, as ice, would be freeze purified leaving concentrated soluble salts in contact with clay minerals. The effect of the concentrated salts might be to aid the clay flocculation process.

The process of flocculation results in the development of clay aggregates which increases the effective particle size of the sample generally. This might help to explain why the frozen sample showed far fewer desiccation cracks when a small sample was dried. This follows the principle that coarser grained material normally develops fewer desiccation cracks when dried.

Photographs of the frozen and non-frozen material show the clay minerals clearly as plates of various sizes. The slabs and needles are probably gypsum. The theory of flocculation or agglomeration of the clays is not clearly supported by these photos. What is evident, but rather subtle, is that the clay particles in the frozen material are generally finer grained, and they seem to be more densely packed. Possibly freezing has comminuted or broken up the clay minerals.

Photos taken at higher magnifications of frozen material show the development of a few clay aggregates made up of fine grained clay particles. This might support the idea that freezing breaks up some of the clay plates into smaller pieces, which then proceed to agglomerate. The water trapped between the original clay plates would be liberated in the process.

A third mechanism which may account for the different physical properties of the two samples has been advanced by various other researchers (see references listed in 5.5.2). Experimental evidence indicates that large suction pressures are generated in fine grained soils during freezing. These suction pressures cause increased effective stresses and subsequent consolidation of the sample. Consequently, it is expected that mechanical breakage at the higher effective stresses may be combined with more brittle deformation characteristics of the clay particles to cause a reduction in particle size and a more densely packed structure.

5.5.6 Discussion

The simple laboratory tests conducted on the Key Lake tailings generally substantiate the anticipated behavior of the materials as outlined in Section 5.5.2. Generally, a significant increase in the total water recovered and the dry density of solids was noted.

Samples that were frozen, thawed and remixed showed only slight improvements over the control tests, since the available pore fluids were redistributed in the agitated and unconsolidated slurry. The small increase in density and water recovery is likely due to consolidation of clay chunks and the formation of discrete clay flocs which were not broken up on subsequent mixing.

It is also evident that removal of the supernatant prior to freezing does not change the characteristics of the thawed slurry as indicated in Table 5.2 and Figure 5.11 for cylinders c and d.

An indication of the influence of the number of freeze-thaw cycles can also be determined by comparing cylinders j and k. It is evident that the majority of consolidation (approximately two thirds) occurs in the first freeze-thaw cycle.

The laboratory tests are idealized approximations of field conditions only. One significant factor that could not be modeled simply is the influence of the freezing direction on the structure of the thawed tailings. The tailings cylinders were frozen outdoors, so that the freezing directions came from the top, bottom and radially. The observed distribution of ice lenses in the cylinders will not be representative of field conditions, since the majority of ice lenses in the field will form perpendicular to the freezing direction. Therefore, it was impossible to realistically assess the influence of freezing and thawing on the structure and permeability of the tailings samples.

5.6 MOISTURE, SOLIDS CONTENT AND DRY DENSITY DETERMINATIONS

Determination of the in-situ moisture and solids content of tailings was carried out on core samples, on spade samples and on cores extracted in advance of spade holes. Dry density was calculated from the solids content using the relationship:

$$\text{Dry Density} = \frac{1}{1/G + W/S} \ (t/m^3)$$

where W = moisture content (%) (wt. of water/wt. of solids)
G = specific gravity
S = degree of saturation (Assumed 100%)

This equation has been used with a specific gravity of the solids of 2.64. The assumption of 100% saturation is reasonable for a conventional saturated tailings material. When the sample falls below 100% saturation, air rather than water fills some of the voids. Consequently the sample volume is under estimated and the dry density is over estimated. The error is small for samples close to saturation but increases with the degree of unsaturation.

TABLE 5.3

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

SUMMARY OF DENSITY MOISTURE AND SOLIDS CONTENT VALUES

Sample Date	Sample Type	Sample Location		Measured		Calculated
				Moisture Content (%)	Solids Content (%)	Dry Density (t/m^3)
June 2	Bulk	Site A		47	68.3	1.19
June 2	Cores	Site A	Av	135	42.6	0.58
			Hi	208	52.5	0.78
			Lo	91	32.5	0.41
July 12	Bulk	Site A		106	48.7	0.70
July 12	Bulk	Site A		64	61.2	0.99
July 13	Bulk	Traverse (A1)		212	32.1	0.40
July 13	Bulk	Traverse (A2)		129	43.7	0.60
July 13	Bulk	Traverse (A3)		176	36.2	0.47
July 13	Bulk	Traverse (A4)		127	44.0	0.61
July 14	Bulk and Core	Traverse (B1)	Av	166	37.6	0.49
			Hi	233	43.5	0.60
			Lo	130	30.0	0.37
July 14	Bulk and Core	Traverse (B2)	Av	153	39.5	0.52
			Hi	221	55.3	0.84
			Lo	81	31.2	0.39
July 13	Bulk	Traverse (B1)	Av	44	69.3	1.22
			Hi	69	75.9*	1.44*
			Lo	32@	59.1	0.94

				Measured		Calculated
Sample Date	Sample Type	Sample Location		Moisture Content (%)	Solids Content (%)	Dry Density (t/m^3)
July 13	Bulk	Traverse (B2)	Av	194	34.0	0.43
			Hi	242	38.3	0.51
			Lo	158	29.3	0.36
July 13	Bulk	Traverse (B3)	Av	167	37.4	0.49
			Hi	196	47.3	0.67
			Lo	111	33.8	0.49
July 13	Bulk	Traverse (B4)	Av	114	46.8	0.66
			Hi	155	60.3	0.97
			Lo	66	43.8	0.66
August 24	Core	Site A	Av	170	37.1	0.48
			Hi	182	48.6	0.70
			Lo	89	28.7	0.35
August 24	Core	Site A	Av	170	37.1	0.48
			Hi	265*	59.1	0.93
			Lo	69	27.4@	0.33@
October 25	Core	Site A	Av	161	38.3	0.50
			Hi	204	53.7	0.80
			Lo	86	32.9	0.41
October 25	Core	Site A	Av	89	53.0	0.79
			Hi	175	75.3	1.42
			Lo	33	36.3	0.47
October 25	Core	Site A	Av	119	45.7	0.64
			Hi	174	58.3	0.91
			Lo	72	36.6	0.47
			Average	134	45	0.64

* Maximum Observed Values.

@ Minimum Observed Values.

Av, Hi and Lo. refer to values obtained from several samples at a single location.

Bulk - samples from spade hole.

Core - samples from core sampler.

A4 (typical) - see Figure 3.4 for sample locations.

Moisture Content (%) = wt. of water x 100/wt. of solids

Solids Content (%) = wt. of solids x 100/(wt. of solids + water)

Dry Density = (wt. of solids)/((wt. of solids/solids S.G.) + wt. of water)

As discussed in Section 3.5 data from the moisture-density probe was unreliable and has not been included in this report.

Results from all samples are included in Appendix B as Tables B7 to B10. A summary of in-situ data is included on Table 5.3 while the effects of drying times and temperatures on moisture content determinations are included on Table 5.4.

5.6.1 Drying Time and Temperature

As indicated on Table 5.4 a significant under-estimation of moisture content (and thus over-estimation of solids content and dry density) could occur if drying temperatures were maintained too low or drying times too short. For this work, as for the Phase I study, all samples for moisture determination were dried in an automatically controlled forced convection oven set at 105°C for a minimum period of 16 hours. Several larger samples were dried for longer periods until weight losses had stabilized. As discussed later in Section 5.9 weight loss from gypsum dehydration was not likely to be significant under such controlled temperature drying conditions.

5.6.2 Observed Dry Densities and Solids Content

The calculated dry density based on measured moisture contents ranged from a high of 1.44 t/m^3 to a low of 0.33 t/m^3 with an average of 0.64 t/m^3 (Table 5.3). These correspond to solids content ranging from a low of 27.4% to a high of 75.9% with an average of 45%.

The range in observed densities and moisture contents were broader than observed for Phase I for two reasons:

TABLE 5.4

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

VARIATION IN TAILINGS MOISTURE CONTENT WITH DRYING TIME AND TEMPERATURE

		Number of Samples	Additional Water Loss (% of Initial Water Loss) (Average)	Range of Additional Losses
A)	Initial Samples Dried 16 hours at 60°C	8		
	6 hours additional drying at 105°C		8.7%	6.5% to 11%
	18 hours further drying at 105°C		0.6%	0% to 1.3%
B)	Initial Sample Dried 8 hours at 105°C	9		
	16 hours additional drying at 105°C (24 hours total)		4.2%	1.2% to 5.7%
C)	Initial Sample Dried 16 hours at 105°C	3		
	8 hours additional drying at 105°C (24 hours total)		0.7%	0% to 1.2%

(a) The use of snow shoes allowed much wetter areas of the facility to be reached and sampled.

(b) Much of the near surface material sampled had been through a freeze-thaw cycle the previous winter and at the time of sampling would have been unsaturated.

Moisture content of such samples would be low and some were observably unsaturated. The calculated dry density values would be erroneously high due to under-estimation of the bulk sample volume, i.e. a sample with a 50% solids content would have a calculated dry bulk density of 0.72 t/m^3 if 100% saturation was assumed but if saturation was only 75% the true density would be 0.58 t/m^3.

5.6.3 Additional Observations

Further field observations are summarized below:

- Major variations in density and moisture content are widespread throughout the facility both laterally and vertically. Probes pushed into the tailings during a search for ice lenses showed layers of high resistance and low resistance materials. Digging in several locations showed some correlation with the interlayering of fresh tailings with apparently previously frozen and thawed tailings. Other factors contributing to layering will include variations in the tailings physical characteristics and the degree of drying and consolidation achieved within individual layers.

- Although not well supported by data, field observation indicates that the tailings surface on the north side which saw no tailings deposition between October 1984 and September 1985 became progressively more slick with each visit, particularly immediately after rain showers. This may possibly have resulted from the deposition of dissolved solids during the evaporation of water from the tailings surface.

- The freeze-thawed tailings are easily compressible as indicated by the following observations:

(i) Pedestrian traffic on thawed and dried tailings left full foot prints. Boot heels could be kicked in several inches without effort. Resaturation of the upper tailings layers could not be induced by jumping on or pounding the surface.

(ii) A hollow thick walled 25 mm plastic probe was pushed through a 1700 mm depth of tailings until the sand of the underlying filter blanket was penetrated. The length of sample in the probe was measured to be only 680 mm. The sampler was removed. Sand at the base of the probe confirmed penetration of the filter blanket. Based on the core length of 680 mm the volume would appear to have been reduced during sampling to only 40% of the initial value. It is probable that some part of this volume reduction was due to material being displaced from in front of the probe and not being collected in the tube. However, a significant part of the volume reduction likely results from large voids caused by melting of segregated ice. Other observations of sample volume reduction were made in most locations where freeze-thawed tailings were cored.

5.7 SPECIFIC GRAVITY

Tests were carried out on two core samples using drying temperatures of 45°C and 220°C with high purity methanol being used as the pycnometer liquid. The results are summarized below:

TAILINGS SOLIDS SPECIFIC GRAVITY

Sample	Dried at 45°C	Dried at 220°C
A1	2.39	2.67
A4	2.23	2.65
Average	2.31	2.66

The values for drying at 220°C are close to the value of 2.64 which is the average value for most previous tests on Key Lake tailings using water and 105°C drying temperatures. The slightly higher average value of 2.66 may be attributed to minor water loss resulting from gypsum dehydration at the higher than normal oven drying temperature of 220°C.

The low values resulting from drying at 45°C are attributed to incomplete removal of free water. As indicated in Section 5.6.1, additional water losses of up to 11% were observed when drying temperatures were increased from 60°C to 105°C.

This work confirms that a value of 2.64 for tailings solids specific gravity is a reasonable assumption for the Key Lake tailings and indicates that the average value of 2.94 determined for the Phase I study was not representative.

5.8 PARTICLE SIZE DISTRIBUTION

As reported in the Phase I study, it was not possible to complete meaningful hydrometer size analyses of the minus 200 sieve fraction of the Key Lake tailings. Dispersing agents normally used for soil testing were unable to influence the material resulting in the rapid settling of agglomerated silt and clay size particles.

For the Phase II study efforts were made to prepare samples of discrete particles suitable for size determination using optical microscopes to count particle sizes. This was not possible owing to the visible agglomeration of discrete particles. Dispersing agents were again used both alone and in combination with ultrasonic agitation. Agglomerated particles from the two tailings samples B1 and B4 that were studied again could not be separated. It was concluded that the gypsum present formed a bonding matrix.

Conventional wet screen sizing was also carried out on grab samples from the eight cores described in Section 3.3 and on a sample of leach tailings taken from the process circuit prior to any neutralization. The results are plotted on Figure 5.12 and tabulated in Appendix C. It was observed by the technician that "the +0.5 mm and +1.0 mm fractions appeared to be clay fractions that were too hardened to break during wet sieving".

The plots on Figure 5.12 show the wide variation in screen size distribution to be expected from in-situ tailings. The observed percentage passing a 325 mesh screen ranged between 35% and 85% dry weight compared to only 22% for the leach residue sample. A major input to the fine particle fraction of the tailings would appear to occur after the leach step, during the lime addition of the bulk neutralization processes. Variations in the size distribution appear unrelated to the location on the tailings beach.

It can be concluded that grain size distribution data for the Key Lake tailings is highly variable and must be regarded with suspicion due to particle agglomeration.

5.9 THERMOGRAVIMETRIC ANALYSIS AND DIFFERENTIAL SCANNING CALORIMETRY

In an attempt to identify the source and extent of non free moisture weight losses from the tailings material during laboratory drying and at higher

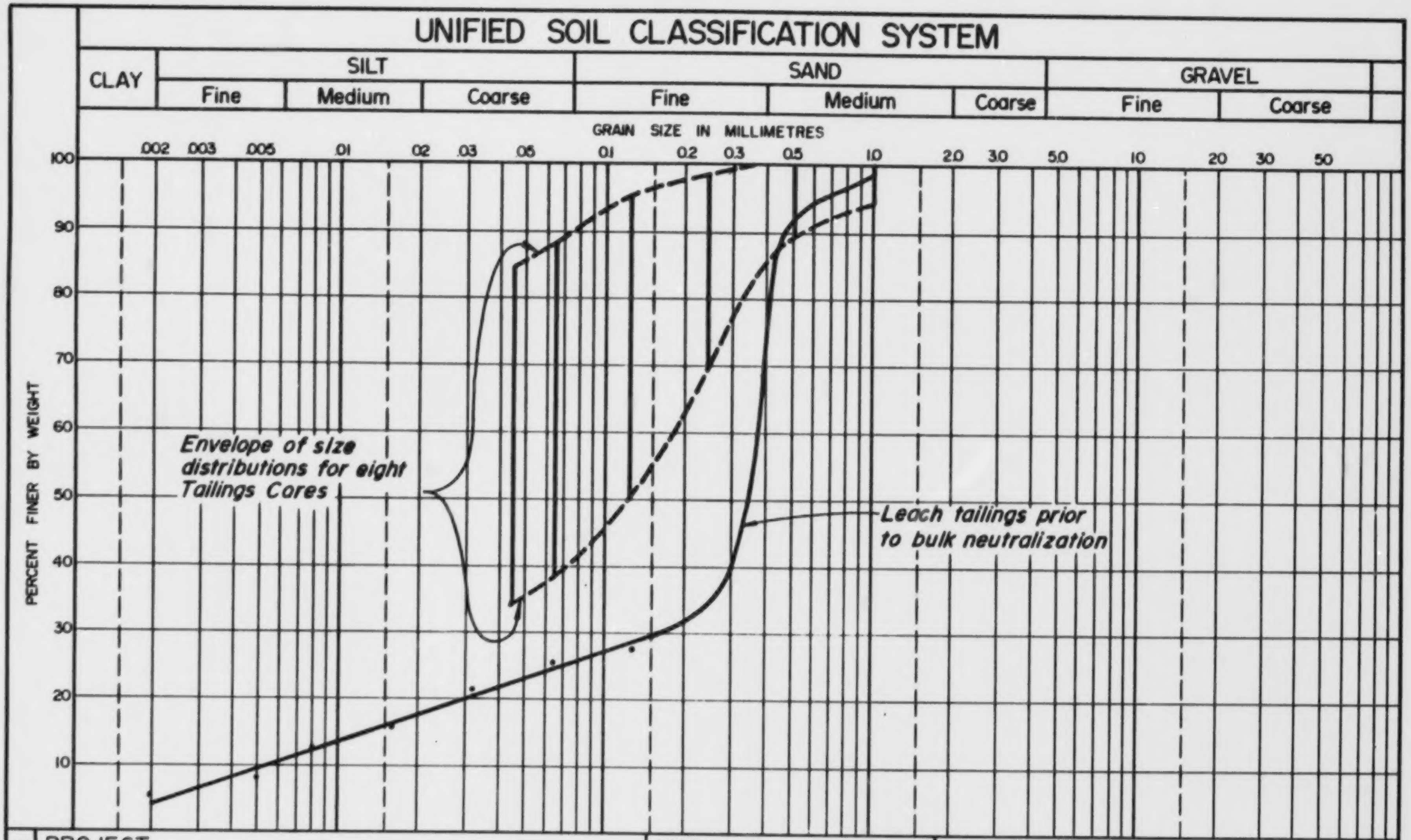


FIGURE 5.12

PROJECT:

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SIZE DISTRIBUTION OF TAILINGS SAMPLES

SAMPLE No.

DATE JUL. 1985

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temperatures, a series of Thermogravimetric Analyses (TGA) and Differential Scanning Calorimetry (DSC) tests were made on samples of tailings. Detailed results and discussions are included in Appendix F.

The major quantitative results are summarized below:

Sample	Moisture Loss (%)		Indeterminate Losses (%) (+200°C)
	Free Moisture	Gypsum Dehydration	
A2	10.4	4.8	5.9 (to 700°C)
A3	11.3	4.7	5.4 (to 690°C)
B2	2.6	4.5	4.1 (to 600°C)
B3	5.1	4.3	4.0 (to 600°C)

Note: Moisture losses are expressed as a percentage of the initial sample weight after vacuum drying.

Major observations arising from the work included the following:

- Removal of free moisture from the samples was not satisfactorily completed until samples were heated to at least 90°C. As discussed in Section 5.6.1, heating at 105°C for 16 hours would normally suffice.

- Additional water loss from gypsum dehydration ranged between 4% and 5% of the initial sample weight after vacuum drying. This loss was substantially complete at 120°C and procedes more rapidly as temperatures are increased. A small non free moisture loss could therefore occur from drying ovens that run too hot.

- Because the free moisture content of field tailings samples is much greater than that of the vacuum dried samples used in the laboratory TGA study, weight loss due to gypsum dehydration at oven drying temperatures of 105°C is probably insignificant.

- Further weight loss ranging between 4% and 6% of the initial sample weight occurred as samples were heated to 600°C or greater.

- Only gypsum dehydration and free moisture losses could be correlated with DSC and TGA data. Clay (montmorillonite) and jarosite decomposition may contribute to water losses in the +200°C range but specific decomposition peaks were not identifiable in the samples provided.

- Sufficient variation occurred in the TGA test results to confirm that results from the few samples evaluated should not be generally applied to all Key Lake tailings samples. We may conclude that the drying of Key Lake tailings at 105°C for 16 hours will not normally produce significant weight loss other than that from free moisture.

5.10 RADIATION MEASUREMENTS

5.10.1 Gamma Radiation

During 1985 several spot measurements for gamma radiation (mrad/hr) were obtained and gamma profiles from the discharge to the stored water pond were obtained. The spot measurements are summarized in Table 5.5 and the profile results are summarized in Figure 5.13.

As a general rule gamma readings decrease with increasing moisture content and proximity to the embankments. Lower gamma values near the external embankments may result from partial segregation of coarse/slime fractions. As a ground rule, the primary gamma emitters, Ra-226 daughter products, tend to concentrate in the slime fraction.

Readings obtained during 1985 are comparable with the data obtained in 1984.

5.10.2 Radon Exhalation

As part of the Phase II program, radon exhalation measurements were made during five campaigns. Table 5.6 presents a summary of the details pertaining to each of these sampling campaigns. Of the eleven exhalation determinations carried out during these campaigns, five were at Site A, three were at other locations on the tailings and three were at non-tailings locations.

The exhalation rates from the surface were determined using the same accumulation technique as in the Phase I study. However, for the Phase II study the accumulating device was equipped with two radon integrating detectors versus three detectors as in the Phase I study.

Section 5.7.2 of the Phase I report outlines the data interpretation and discusses the theory behind this radon exhalation measurement system.

5.10.3 Discussion of Results

The radon exhalation (flux) rates measured at the various sampling locations are summarized on Table 5.6. The flux rate at Site A ranged from a low of 2.4 Bq/m^2.s in September to a high of 64.3

TABLE 5.5

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GAMMA RADIATION READINGS (mrad/hr)

	Site A	Site B	Near Spraybars	Discharge
June 2	3.6	2.5	3.1	1.1
July 11	4.3	3.3	---	---
July 14	---	2.4	2.3	---
August 26	4.1	---	---	---
September 27	3.3	3.5	---	---
October 26	4	3.5	---	---

Note:

Readings taken at 1 metre above tailings surface.

TABLE 5.6

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SUMMARY OF RADON EXHALATION MEASUREMENTS - PHASE II

Date (1985)	Start Time	Location	Description	Radon Flux Bq/m^{-2}.s(pCi/L.s)	Data Correlation	Comments
May 31	0820	A	Site A	10.2 (276)	0.99	- tails dry and cracked
May 31	1352	TR	Till road away from tailings	*	-	- road dry
June 2	0909	6BAR	Near fresh tailings	8.6 (232)	0.99	- beach damp - 6 bars from S corner
June 2	1421	4BAR	Near tailings discharge	*	-	- beach damp and soft - 4 bars from S corner
July 11	1337	A	Site A	3.9 (106)	0.99	- dry cracked - old tailings deposited October 1984
July 12	1315	L2	Line 2	1.8 (48)	0.76	- centre of south side - dry winter tailings
July 13	0800	BNCH	Bench above monitoring hut	*	-	- dry sandy till
August 23	1320	A	Site A	7.3 (198)	0.97	
August 24	0820	MH	Monitoring hut floor	*	-	
September 29	1355	A	Site A	2.4 (63)	0.94	- surface thawed after being frozen in morning
October 26	1443	A	Site A	64.3 (1735)	0.98	- surface frozen

Note:

* Calculated radon flux invalid based on data supplied, see text for discussion.

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SURFACE GAMMA READINGS (mrad/hr.) AUGUST 26, 1985

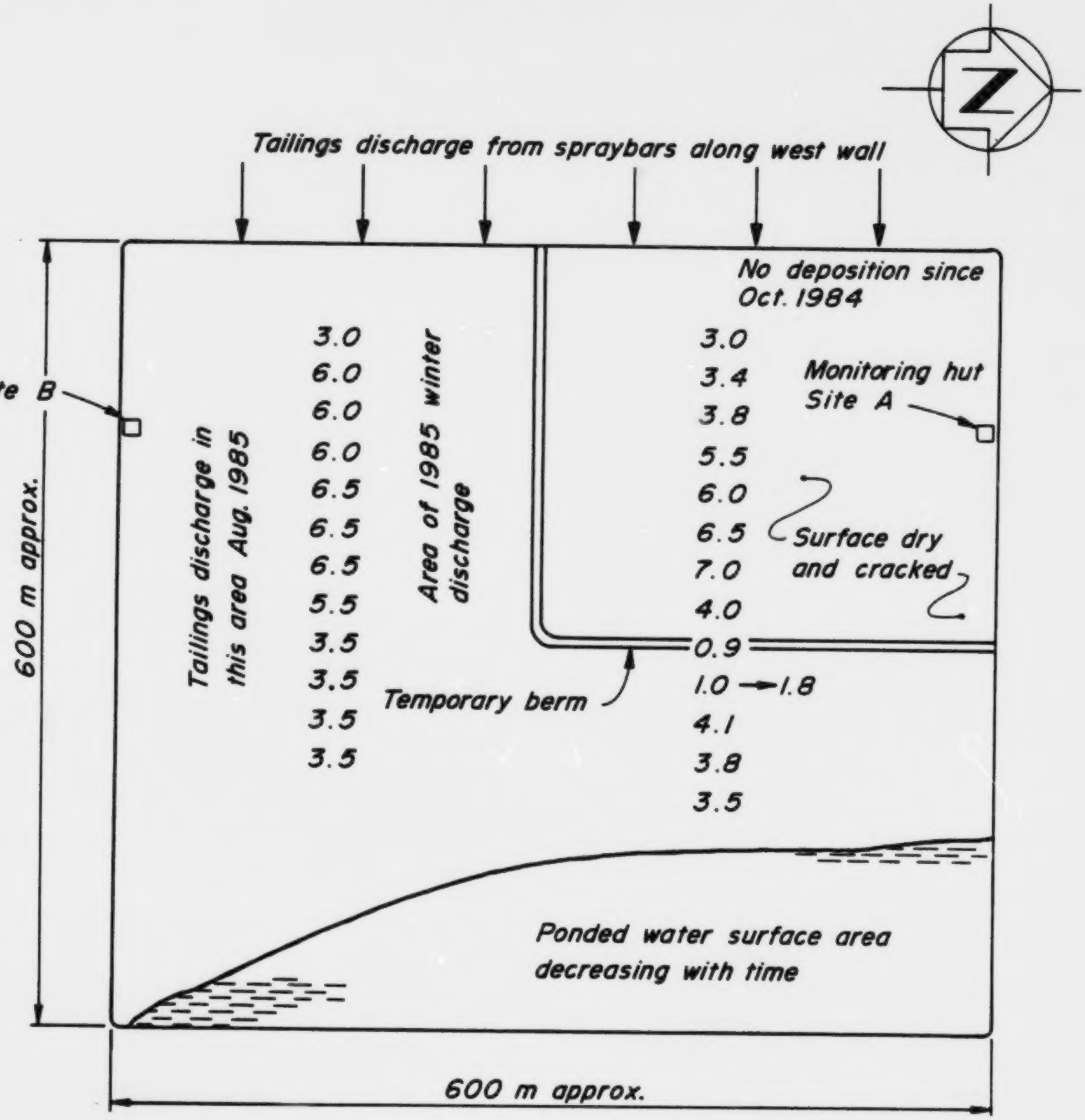
N
Tailings discharge from spraybars along west wall
No deposition since Oct. 1984
600 m approx.
Site B
Tailings discharge in this area Aug. 1985
3.0
6.0
6.0
6.0
6.5
6.5
6.5
5.5
3.5
3.5
3.5
3.5
Area of 1985 winter discharge
Temporary berm
3.0
3.4
3.8
5.5
6.0
6.5
7.0
4.0
0.9
1.0 → 1.8
4.1
3.8
3.5
Monitoring hut Site A
Surface dry and cracked
Ponded water surface area decreasing with time
600 m approx.

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FIGURE 5.13

Bq/m^2.s in October. Of the other sites tested only the Line 2 and fresh tails near bar 6 sites demonstrated a positive radon flux with rates of 1.8 and 8.5 Bq/m^2.s respectively. The radon concentrations measured at the remaining four sites either decreased with time or did not change significantly.

To illustrate these results, radon concentration versus time for these three test site groups are plotted on Figures 5.14 to 5.16. Figure 5.14 pertains to the radon concentrations measured at Site A. Figure 5.15 pertains to the Line 2 and the fresh tails at bar 6 sites. A review of these figures shows the increase in radon levels with time.

Figure 5.16 illustrates the radon concentrations measured at the remaining four sites. A review of this Figure shows that the radon levels were either decreasing or not significantly changing with time. The flux rates for these sites have been identified with an asterisk (*) on Table 5.6. The till bench and monitoring hut site showed no significant change with time, suggesting no measureable radon flux from the surface. The other two sites however showed a steadily decreasing radon level. A possible explanation for this is the fact that immediately prior to the testing at these two sites the radon concentrations measured at the previous test site were extremely high. For example, just prior to the start of the till road test at 1352 hours the final concentration measured at Site A (at 1320 hours) was approximately 370 Bq/L or 10,000 pCi/L. Similarly just prior to the start of the fresh tailings test at bar 4 (at 1421 hours) the final concentration measured at the fresh tailings bar 6 site (at 1230 hours) was approximately 260 Bq/L or 7,000 pCi/L. These high concentrations would have resulted in a significant amount of daughter products plating out on the radon detector surface, which through their decay would exaggerate the actual radon concentration in the accumulator. The more rapid decline in radon levels at the till road

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RADON MEASUREMENTS AT SITE A

RADON CONC (pCi/L) vs TIME (T1+T2)

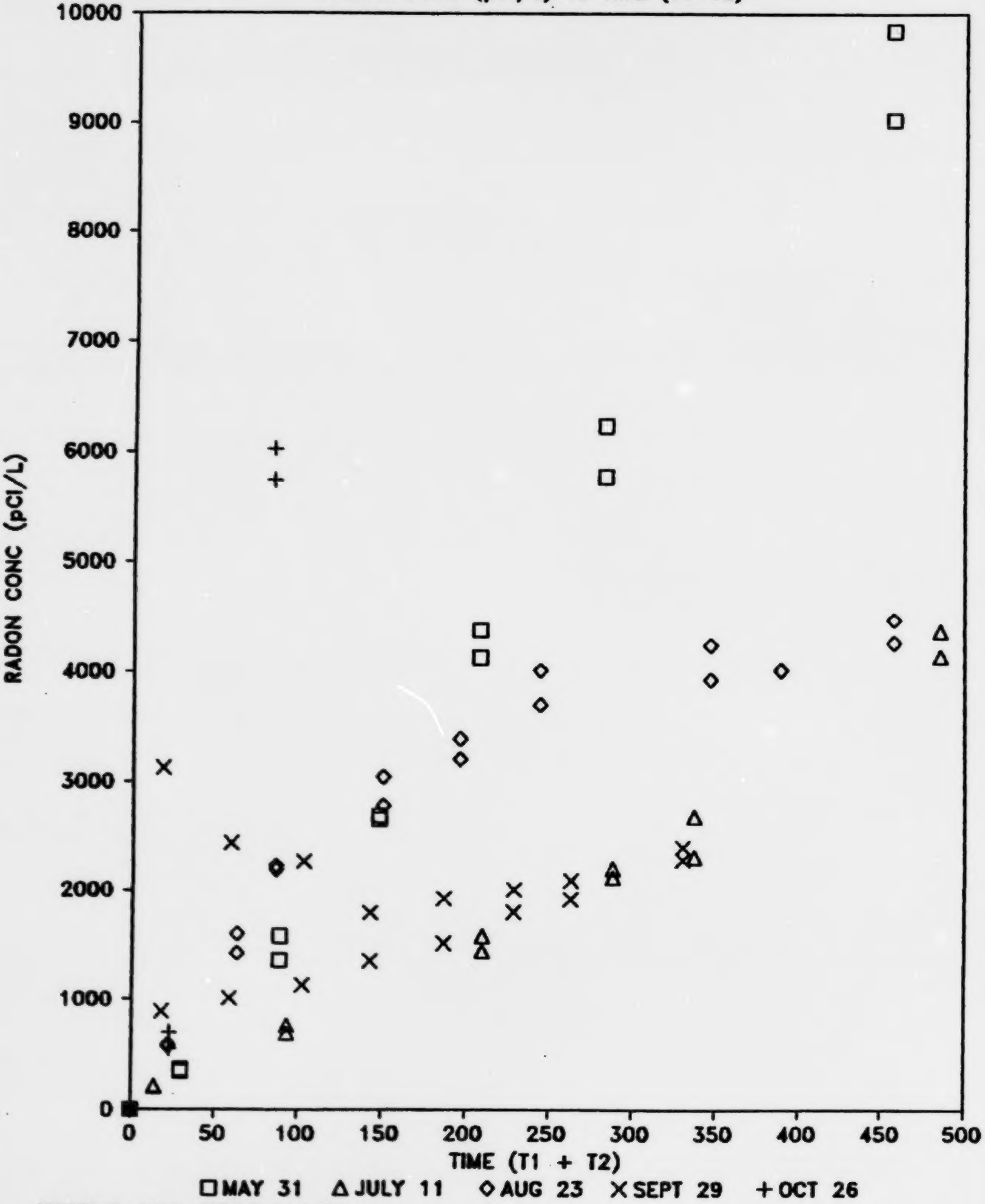

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FIGURE 5.14

MONITORING OF LAYERED URANIUM TAILINGS
PHASE II

RADON MEASUREMENTS AT 6BAR AND L2

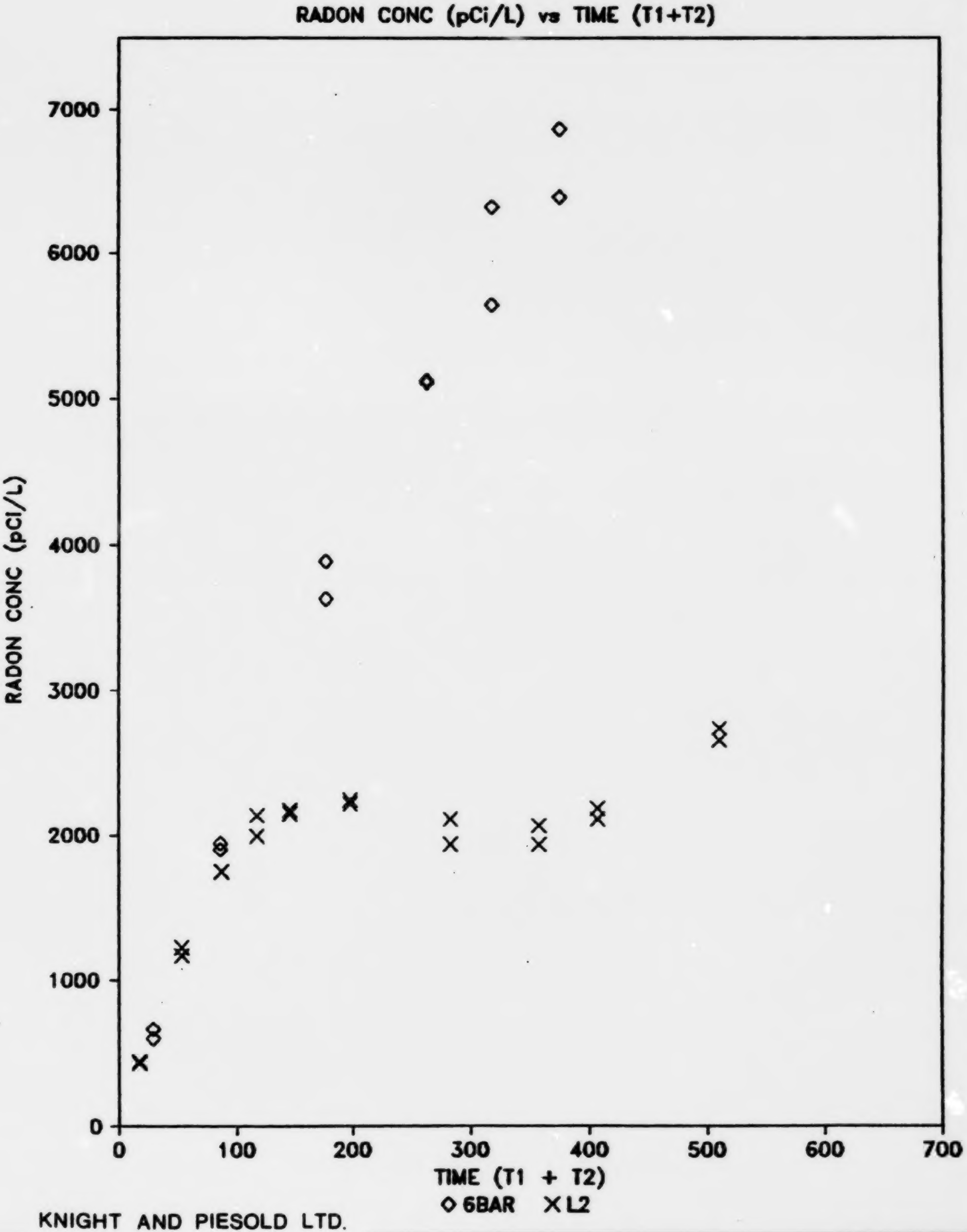

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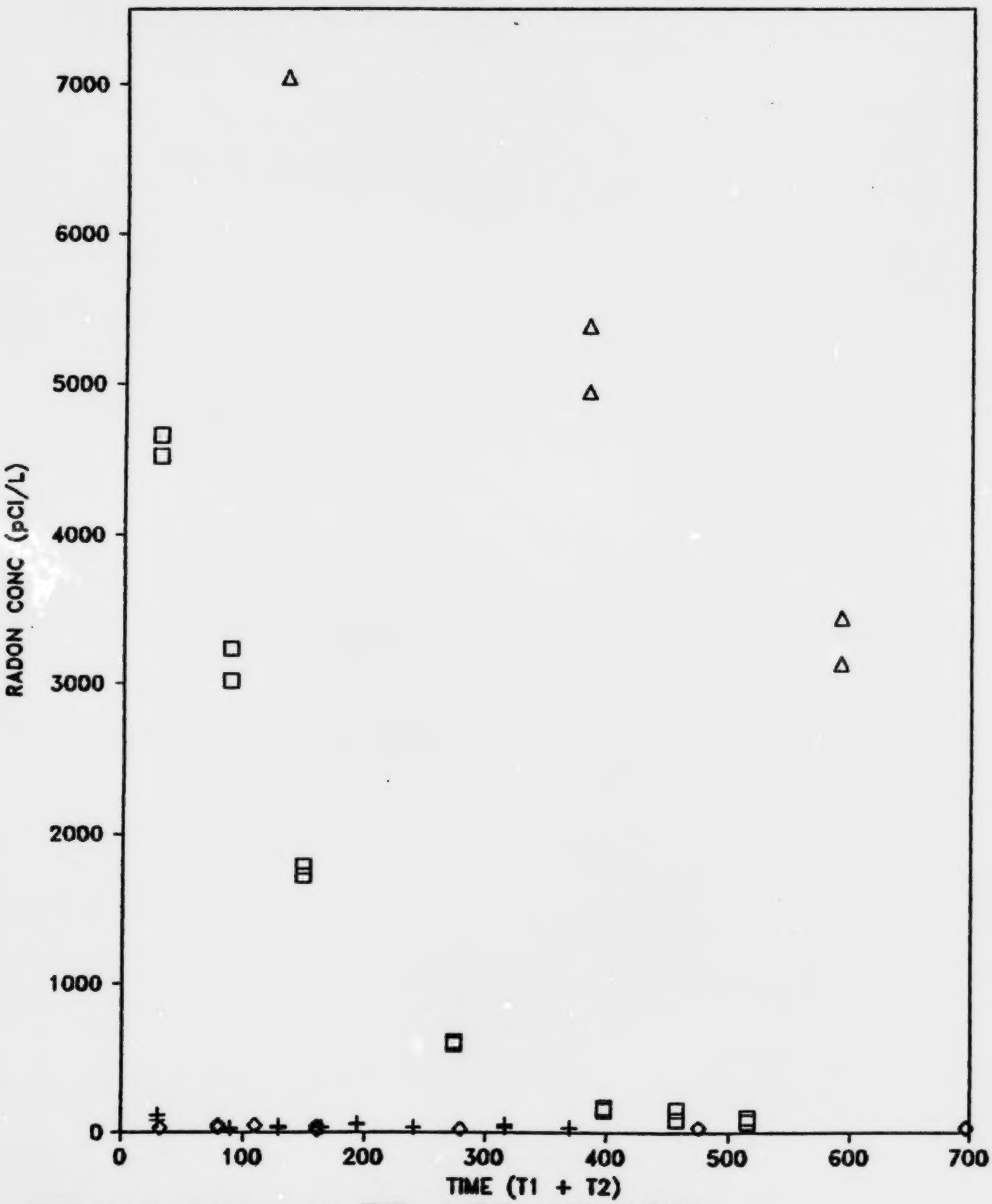
FIGURE 5.15

MONITORING OF LAYERED URANIUM TAILINGS
PHASE II

RADON MEASUREMENTS AT SITES TR, 4BAR, MH AND BNCH



RADON CONC (pCi/L) vs TIME (T1+T2)

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FIGURE 5.16

site suggests that the radon flux into the can was not significant whereas for the 6 bar site the effect of the daughter product decay was offset by the influx of radon into the can resulting in a less rapid decrease in the measured radon level inside the accumulator.

5.10.4 Comparison with Previous Results

The radon exhalation rates measured during the Phase II program were higher than those for the Phase I period. As predicted by the CEA in Appendix XI of the EIS, the flux could vary from 1.1 to 25.9 Bq/m^2.s (30 to 700 pCi/m^2.s) depending on the state of the tailings surface. During Phase I the tailings generally were saturated whereas during Phase II the tailings (at Site A) were dry and cracked. For the dry surface condition the CEA predicted levels in the order of 9.3 Bq/m^3.s for the extensively cracked surface. The average of the May, July, August and September radon flux measurements at Site A was 6.0 Bq/m^2.s (162 pCi/m^2.s). The October flux measurement of 64.3 Bq/m^2.s at Site A is not included in the average because it is well above the average of the other four measurements by a factor of 10. This flux rate is more than twice the rate predicted by the CEA for an extensively cracked tailings surface.

It should be noted that as predicted in the Phase I study the drier surface of the tailings is supporting a higher radon flux rate than for the saturated tailings tested during Phase I. However, the flux measurement of 8.6 Bq/m^2.s (106 pCi/L.s) for the fresh damp tailings site near the sixth bar is well above previous measurements on similar tailings and also well above the CEA predicted levels.

A summary of the radon exhalation data collected is presented in Appendix B.

SECTION 6.0 - APPLICATION OF FIELD DATA

6.1 TAILINGS DEPOSITION

For most of the monitoring period tailings discharge was into the south half of the facility resulting in the burial of Site B except for temperature monitoring.

Site A, when viewed in late May 1985, was extremely dry on the surface with a crumbly cracked appearance. The surface was relatively flat without the gross hummocking and ridges observed in other parts of the facility. In general surfaces tended to be more broken with distance away from the discharge point. Tailings had been deposited over Site A up until October 1984. These had subsequently frozen and then thawed prior to the first site visit in late May 1985. No further deposition was made over Site A until mid September 1985. Consequently these tailings were exposed to optimum drying conditions throughout the summer of 1985. Also during the Spring and Summer of 1985 the standing water pond in the north east corner of the facility was drawn down to a low level, thereby enhancing water removal through the underdrainage system. During late May 1985 when pressure sensors were installed at Site A, the underlying tailings were observed to be ice free but saturated. Tailings cores extracted at that time for moisture and density determination and during subsequent visits, were extremely variable and gave no strong evidence of an overall drying trend. Pore pressure data available in late August, showed the existence, at that time, of significant negative pore pressures, indicating unsaturated soil conditions in much of Site A. This situation continued until fresh tailings were deposited over the site in mid September.

General observation indicated an on-going drying of the surface. However, precipitation did not run off, but either ponded briefly before disappearing or else rapidly percolated into the tailings.

The porous and crumbly surface in addition to allowing infiltration of precipitation may also reduce capillary rise of moisture to the surface, for subsequent loss by evaporation. Evaporation is not completely restricted, however as the surfaces of the tailings frequently developed colour, presumably due to surface deposition of soluble minerals. The surfaces also become slick after rainfall.

Visual observation of tailings cores showed layers of apparently wetter and drier material. This together with the greater and lesser forces required for penetration by samplers or probes indicates the probability of wide variations in both vertical and horizontal permeabilities of the tailings.

It is surmised that a combination of natural layering of the tailings during deposition, variations in tailings physical characteristics evaporative drying, together with local consolidation and porosity resulting from winter freeze and spring thaw have resulted in a complex series of tailings layers.

The evidence for extreme heterogeniety within the tailings facility suggests that pressure sensors may see pressure variations due to variations in the layers of material immediately around them, rather than bulk properties of the tailings. The pressure sensor readings at Site A show some systematic variations in pressure that are related to overlying tailings deposition and drainage, but also variations that are more difficult to interpret. These latter variations may reflect layering in the tailings.

The deposition of tailings over Site A was accompanied by an increase in pore pressure for all sensors. For sensors P5, P6 and P9 the recorded pressure was significant and probably closely related to the build-up of seepage water in the underlying filter blanket. For two sensors, P7 and P8 the rise was minimal. This may be a result of the higher location within the tailings for sensor P7, or possibly sensor malfunction for sensor P8.

As discussed in Section 5.4 of the Phase I report and also in this report, an elevated phreatic surface accompanied tailings deposition over Site A with a slow fall after deposition had ceased. Drawdown into the pumped sump under Site A, induced water inflow from outside the test area (Figure 5.9). Consequently the seepage recovery is greater than that expected only from tailings placed directly over the site. The elevated phreatic surface most probably results from the slow removal of seepage water through the filter blanket underlying Site A and the surrounding tailings. Mounding of ground water occurs due to the wide spacing of collector drains. Because Site A is midway between drains significant positive hydrostatic pressures are observed in the standpipes at such times. At the final site visit, one month after tailings deposition had ceased, no local phreatic surface was detected within the tailings. The tailings had also visibly consolidated and pore pressures had fallen back, generally to pre-tailings deposition values or lower. At this time diurnal freezing and thawing of the tailings surface was also exerting moisture removal and consolidation effects sufficient to be monitored on all pressure sensors.

6.2 FREEZE-THAW EFFECTS

Field observation and data collected during Phase I and Phase II of this project indicates that freezing and thawing cycles have significant effects on the deposited Key Lake tailings.

6.2.1 Surface Topography

The significant ridges and hummocking that are observed in areas where winter deposition has occured may be due in part to warm incoming tailings creating or keeping open channels through otherwise frozen tailings, or ice. Frost heave or similar effects are likely significant.

6.2.2 Subsurface Structure

Laboratory test work and field observation confirms the porous, open structure of frozen and then thawed tailings. Differences in morphology occur due to such factors as grain size distribution and freezing and thawing conditions (i.e. frost or winter freeze, thawing under water or under drained conditions). Observations to date indicate that the tailings facility does not freeze to full depth. It is probable therefore that vertical heterogeneity within the facility will be further complicated by freeze-thaw tailings interlayered with unfrozen materials. The complex subsurface structure may influence many other components of tailings behaviour as outlined below.

6.2.3 Water Recovery

As described in Section 5.5 freeze-thaw effects have the potential for increasing water released from the tailings in the facility thereby increasing water recovery. The open porous structure of thawed tailings will result in higher permeabilities and may also decrease the pathways for capillary rise of water to the surfaces. Local infiltration would thereby be increased and evaporation from the surface probably decreased. This would add to the water retained in the facility and might further increase the water recovery. Field observation confirmed rapid infiltration of precipitation into thawed tailings.

6.2.4 Tailings Density

Both field recovered freeze-thawed tailings and oven dried cores of previously saturated tailings material exhibit low bulk density, due to the extremely high porosity of the material. Unless undisturbed core samples are available, thereby allowing direct measurement of soil volume, the dry density is calculated based on the weight of solids and water, the known solids specific gravity and assuming complete saturation. As described in Section 5 calculated density is increasingly over estimated as soil moisture falls below saturation.

For this reason care is necessary in comparing the density of cores of calculated volume, particularly when non-saturated conditions may prevail. The wide variation in dry density cited for this work may stem in part from the use of calculated volumes, and the impossibility of simply determining the level of saturation of samples. Measuring of core volumes obtained from cores that are extracted from samplers would appear to offer a solution but it is also inaccurate because of the observed compression that occurs during sampling and extrusion of the Key Lake tailings material and the distortion of soft material.

The observed compression, although currently unquantified, suggests that with increasing depth of burial, on-going settlement and increasing density could be expected from freeze-thawed material.

SECTION 7.0 - CHEMICAL AND MINERALOGICAL PROPERTIES - TAILINGS SOLIDS

7.1 CHEMICAL/MINERALOGICAL COMPOSITION

The elemental composition of the tailings solids is given on Tables 7.1 and 7.2. This elemental composition was used to estimate the mineral make-up of the tailings mass by solving a series of molar composition balances. In 1984, mineralogical data were also available for comparison. Undoubtedly, the most common mineral in the tailings is quartz (SiO_2) comprising, on the average, 38% of the solids. Quartz appears to have a considerable range from 35% to 50%. The second group of silicate containing minerals includes the aluminum silicates. The most common in the tailings solids are the clay minerals such as chlorite ($Mg_8\ Al_4(Si_6Al_2O_{20}).(OH)_{16}$), illite ($KAl_4(Si_7\text{-}AlO_{20}).(OH)_4$) and albite ($Na\ Al\ Si_3O_8$). On the average, clays make-up 22.6% of the tailings, but range in composition from 10% to 30% for the samples tested. The next major group appears to be the sulphate minerals. Gypsum ($CaSO_4.2H_2O$) constitutes 20% of the tailings solids, while ettringite ($Ca_6Al_2(SO_4)_3(OH)_{12}.26\ H_2O$) averages 5.7%.

At some locations, ettringite is virtually absent. Calcite ($CaCO_3$) is the major carbonate mineral averaging 1.6% followed by $MgCO_3$ at 0.7%. Of the arsenic containing minerals, gersdorffite (NiAsS) and calcium arsenate ($Ca_3(AsO_4)_2.3H_2O$) appear to be the most common. Assuming 70% oxidation of the arsenic moiety, NiAsS is averaging at 0.7% and calcium arsenate at 2.1%. Of the iron minerals, ferric hydroxide ($Fe(OH)_3$) is probably the most common, reporting at a mean value of 4.1%. Nickel is probably present as both an oxide ($NiO.H_2O$) and sulphide (NiS/NiS_2) mineral, the two together average about 3%. Titanium oxide (rutile) constitutes 0.3% of the tailings solids.

There appear to be differences in the average chemical and mineralogical make-up of tailings sampled in 1985 versus 1984 as shown on Table 7.2. The calculated composition indicates less gypsum and silica, but much higher clay content. One should be cautious in the use of these data as mineral balances are very sensitive to chemical analyses and assumed formulae. Considerable substitution can be expected in process-produced compounds, and clays are altered by the leaching process.

7.2 MINERALOGY OF NICKEL, ARSENIC AND RADIUM COMPOUNDS

During 1985, mineralogical studies were performed by SRC (See Appendix D) to evaluate the mineralogy of nickel, arsenic and Ra-226 compounds in the tailings basin. Previous studies had not successfully identified many of these mineral compounds. The 1985 studies identified the same minerals as found during 1984 and no new minerals were identified. The work did however better define where the nickel, arsenic and radium were distributed. The primary results are summarized below.

- Nickel occurs principally in the sulfides NiS (millerite), (Ni,Fe)S_2 (bravoite) and the arsenide (Ni,Fe)AsS (gersdorffite); whereas, arsenic occurs principally in gersdorffite. No information on the mode of occurence of Ra was obtained from this or the previous study.

- Nickel/arsenic ratio of all grain size fractions is similar, indicating that mineralogy is consistent between size fractions.

- Arsenic forms a water soluble mineral of unknown composition.

- Pisoliths contain a considerable amount of nickel and arsenic in their quartz shells.

- Confirmed radium compounds are sparingly soluble.

TABLE 7.1

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

TAILINGS SOLIDS ANALYSIS

Sample Description	A1	A2	A3	A4	B1	B2	B3	B4	Av.	Phase I Av.
Mo ppm	2	1	1	1	1	3	1	1	-	13
W ppm	45	45	35	35	50	25	30	10	34	-
Zn ppm	1030	1220	1290	1380	995	965	815	635	1041	-
P ppm	675	500	445	425	480	380	380	345	453	-
Pb ppm	1700	1290	1130	1290	1740	1460	1430	1020	1383	-
Bi ppm	185	185	165	180	180	175	180	135	173	-
Cd ppm	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	-
Co ppm	560	435	420	455	510	480	480	350	460	620
Ni %	1.90	1.85	1.69	1.77	1.65	1.20	1.43	1.09	1.57	1.77
Ba ppm	380	365	210	290	485	490	240	140	325	-
Fe %	2.66	2.43	2.35	2.31	2.29	1.77	1.94	1.47	2.15	2.20
Mn ppm	230	205	215	195	170	128	133	92	171	-
Cr ppm	115	100	100	100	115	110	145	90	109	-
Mg %	1.09	1.04	1.24	1.10	1.14	0.74	0.92	0.66	0.99	0.82
V ppm	505	400	360	345	420	340	355	265	374	-
Al %	4.00	3.96	3.78	3.51	4.47	3.36	3.79	2.51	3.67	2.76
SiO_2%	40.1	33.9	38.4	42.8	42.0	60.1	57.7	69.8	48.1	24
Be ppm	8.0	7.0	7.0	6.5	7.5	6.0	6.0	3.5	6.4	-
Ca %	7.60	10.20	11.80	10.20	9.84	5.33	5.63	4.02	8.08	7.20
Cu ppm	485	445	410	375	480	395	480	300	421	-
Ti %	0.231	0.164	0.154	0.163	0.221	0.180	0.219	0.161	.187	-
Sr ppm	149	137	131	123	161	132	122	96	131	-
Na %	0.09	0.29	0.12	0.11	0.15	0.20	0.11	0.07	.14	-
K %	0.30	0.37	0.32	0.32	0.42	0.24	0.29	0.20	.31	-
As %	1.2	1.1	1.1	1.1	1.0	0.81	1.0	0.77	1.01	1.10
U ppm	790	580	465	530	490	550	840	1430	709	508
SO4 %	15	16	16	14	12	11	9.9	6.3	12.5	15.3
CO2 % (CaCO3)	0.82	2.4	2.3	2.9	3.3	0.71	0.94	0.97	1.79	2.2
Ra 226 Bq/gm	315	312	224	228	275	246	215	150	246	300
Th 230 Bq/gm	237	262	214	245	264	161	169	118	209	260
Pb 210 Bq/gm	315	329	214	258	311	274	220	141	257	300
Po 210 Bq/gm	300	323	180	230	285	273	209	145	243	250

TABLE 7.2

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

ESTIMATED COMPOSITION OF TAILINGS SOLIDS

		Weight %	
Component	Approximate Formulae	1984 Samples	1985 Samples
Silica	SiO_2	48	38
Gypsum	$CaSO_4.2H_2O$ * $2Ca\ SO_4.H_2O$ *	26	20
Clays, Silicates	$KAl\ (Si_7AlO_{20}(OH)_4$ $Mg_8\ Al_4\ (Si_6Al_2O_{20})\ (OH)_{16}$ $Na\ Al\ Si_3\ O_8$	7.4	23
Ettringite	$Ca_6\ Al_2(SO_4)_3(OH)_{12}26\ H_2O$ *	3.7	5.7
Carbonates	$Ca\ CO_3$, $Mg\ CO_3.3H_2O$	5.0	2.3
Calcium Arsenate	$Ca_3(AsO_4)_2.3H_2O$ *	2.0	2.1
Iron Compounds	Fe_2O_3, FeS_2, $Fe(OH)_3$ *	3.2	4.1
Nickel Compounds	$Ni\ O.H_2O$*, $NiAsS$,$(Ni, Fe)S_2$, NiS	2.8	3.7
Minor	C, TiO_2, Metal hydroxides	2	1

Note: Compounds and percentages should only be as approximations only. Ore minerals and compounds produced in the milling circuit (*) are unlikely to be stoichometric. For further discussion of tailings components see Appendix D, Mineralogy of Tailings Samples.

- There is some evidence that some clay minerals are destroyed in the mill and that new clay minerals that form in the tailings area may incorporate nickel.

- Leaching studies confirm that arsenic is also combined as a heavy metal arsenate such as calcium arsenate. Approximately 40 percent of the arsenic is not leachable and assumed to be tied up as gersdorffite. This confirms previous assumptions in the Phase I work (assumed 30%).

- Much of the nickel is present as a non-soluble sulphide. Some water soluble nickel is present, most probably as a nickel sulphate compound.

- Radium appears to be present as a sulphate and likely as a coprecipitate of barium and possibly lead.

SECTION 8.0 - CHEMISTRY - TAILINGS LIQUIDS

A total of 8 porewater samples were analysed in 1985. The results of the analysis are provided on Table 8.1. The range and average of selected constituents for the 1985 samples are compared with the 1984 results in Table 8.2.

Sampling procedures for the tailings material from which the pore water was extracted are given in Section 3.3.

The primary observations of the 1985 data are:

- Major constituents are calcium and sulphate. The concentrations are the expected concentrations considering equilibria with gypsum as a solid phase.

- Arsenic concentrations suggest equilibria with calcium arsenate as a solid phase to pH = 8.9 (solubility calculated from equilibrium data is 0.5 mg/L as As at pH = 11 and 11.0 mg/L as As at pH = 8.9). Below pH = 8.9, the observed concentrations are less than the equilibrium values for calcium arsenate.

- Molybdenum concentrations appear to depend on the solubility of molybdenum oxide (MoO_3), although the observed values are somewhat higher than predicted from equilibrium models.

- Uranium concentrations of 0.2 - 10 ppb suggest that uranium is present in the reduced (U^{IV}) state.

- Nickel, is near the model predicted level at pH values of 7.5 - 9.0 but is at somewhat higher than predicted levels at higher pH values.

- Ra-226 values in porewater do not demonstrate the same pH dependence as do tailings influent and effluent quality samples.

Table 8.2 illustrates that porewater levels in 1985 for various constituents are substantially different from those measured in 1984, with the primary differences being significant increases in molybdenum, arsenic, nickel, tungsten and radium.

Given the variability between samples collected in 1985, it is not unexpected that the variation between results during different years would also be substantial.

The most puzzling aspect is Ra-226. A plot of pH levels versus Ra-226 levels for 10 influent and effluent samples collected in 1984 and 1985 is shown on Figure 8.1. These have a very strong pH dependence. Similarly a plot of pH versus Ra-226 levels is shown on Figure 8.2 for 14 porewater samples. In this case the relationship is weak and appears to be the reverse of that for the tailings influent and effluent samples.

TABLE 8.1

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

POREWATER ANALYSES

Sample Description		A1	A2	A3	A4	B1	B2	B3	B4
Mo	ppb	1730	950	580	1010	910	1460	2300	3040
W	ppb	1210	560	<250	280	175	1120	1110	590
Zn	ppb	<5	<25	<25	<25	<5	<5	<5	50
P	ppb	115	<250	<250	<250	55	155	60	145
Pb	ppb	5	<25	<25	80	15	25	15	20
Bi	ppb	<10	<50	<50	<50	<10	<10	<10	<10
Cd	ppb	<2	<10	<10	<10	<2	<2	<2	<2
Co	ppb	<5	<25	<25	<25	<5	<5	<5	<5
Ni	ppb	170	355	265	560	85	285	230	355
Ba	ppb	<50	<250	<250	<250	<50	<50	<50	<50
Fe	ppm	<0.5	<2.5	<2.5	<2.5	<0.5	<0.5	<0.5	<0.5
Mn	ppb	<5	<25	<25	<25	<5	<5	<5	<5
Cr	ppb	<50	<250	<250	<250	<55	<50	<50	<50
Mg	ppm	<0.5	<2.5	<2.5	<2.5	<0.5	<0.5	<0.5	<0.5
V	ppb	70	<25	95	60	120	65	75	75
Al	ppm	<0.5	<2.5	<2.5	<2.5	<0.5	<0.5	<0.5	<0.5
Be	ppb	<2	<10	<10	<10	<2	<2	<2	<2
Ca	ppm	615	675	680	765	615	670	675	750
Cu	ppb	35	125	135	100	80	45	55	75
Ti	ppm	<0.05	<0.25	<0.25	<0.25	<0.05	<0.05	<0.05	<0.05
Sr	ppb	845	1860	3180	2740	2120	1000	1690	2360
Na	ppm	71.5	56.0	42.5	57.5	97.0	110	114	128
K	ppm	11.5	19.0	20.5	18.0	21.5	18.5	19.0	29.5
As	ppm	6.420	3.660	1.700	3.140	0.615	7.430	6.000	13.000
SO4	mg/L	1600	1700	1500	1800	1500	1700	1600	1600
pH		9.1	7.5	9.2	7.4	10.9	7.8	8.9	8.9
Cond.		2230	2860	2800	3000	2230	2480	2300	2400
Eh		290	-	-	-	230	320	290	280
U	ppb	3.9	2.4	0.7	2.7	0.2	3.6	8.4	10.0
Alkal (CaCO3)	mg/L	142	-	-	-	129	78	43	-
NH3	mg/L N	-	-	-	-	27	20	18	-
Ra	226 Bq/L	71.6	167.6	102.5	142.6	56.4	53.5	65.3	118.9
Th	230 Bq/L	0.66	0.62	0.62	0.49	1.09	0.89	0.33	0.53

TABLE 8.2

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

POREWATER QUALITY

1985 VS 1984 RESULTS

Constituent	1985 Results Concentration Range	1985 Results Concentration Average	1984 Results Concentration Range	1984 Results Concentration Average
Mo ppb	580-3040	1498	430-1200	790
Cr ppb	50-55	--	--	.005
As ppm	0.615-13.0	6.99	0.2-2.2	1.12
Ni ppb	85-355	288	16-87	54
Pb ppb	5-80	--	20-40	--
Zn ppb	5-50	--	20-32	26
W ppb	175-1210	662	230-250	240
Ca ppm	615-765	681	343-627	567
SO_4 ppm	1500-1800	1625	906-1650	1440
Ra-226 Bq/L	54-167	97	9.5-55	31
Th-230 Bq/L	0.33-1.09	0.65	.08-1.6	0.7
U ppb	0.2-10	4	1.4-5	3.1
pH (units)	7.4-10.9	--	9.33-11.4	--

SECTION 9.0 - RETARDATION AND ATTENUATION PROPERTIES OF NATURAL MATERIALS

9.1 INTRODUCTION

During 1984, an extensive monitoring program was conducted on the Key Lake tailings facility. Data were collected on chemical and physical characteristics of tailings solids, and their mineralogy. Water quality analyses were conducted for influent, effluent, porewater and seepage streams. From this data a preliminary geochemical contaminant model was developed to assess the long-term chemical characteristics of the Key Lake tailings. As a continuation of this study, additional chemical characterization data of tailings solids and liquid streams was collected in 1985 and the study was expanded to include a preliminary evaluation of contaminant transport from the tailings repository.

Seepage from the base of the tailings mass must pass through several engineered and natural materials before reaching any potential receptor. These include sand in the tailings underdrain, the till/bentonite liner material, natural tills and the shallow sandstone bedrock.

The transport of contaminants through engineered and natural barriers composed of natural or modified soils is dependent on the permeability and attenuation characteristics of the materials. The extent to which each natural material acts as a geochemical trap to the water-borne transport of radioactive and non-radioactive contaminants is predominantly a function of the mineralogical composition of the material, the chemical composition of the tailings seepage, and the pH conditions that are established as the seepage penetrates the barrier material.

A number of mechanisms are responsible for contaminant retardation in soils including adsorption, coprecipitation, hydrous metal oxide complexation, organic matter complexation, colloid formation and microbial effects.

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MONITORING OF LAYERED URANIUM TAILINGS
PHASE II

INFLUENT AND EFFLUENT TAILINGS WATER

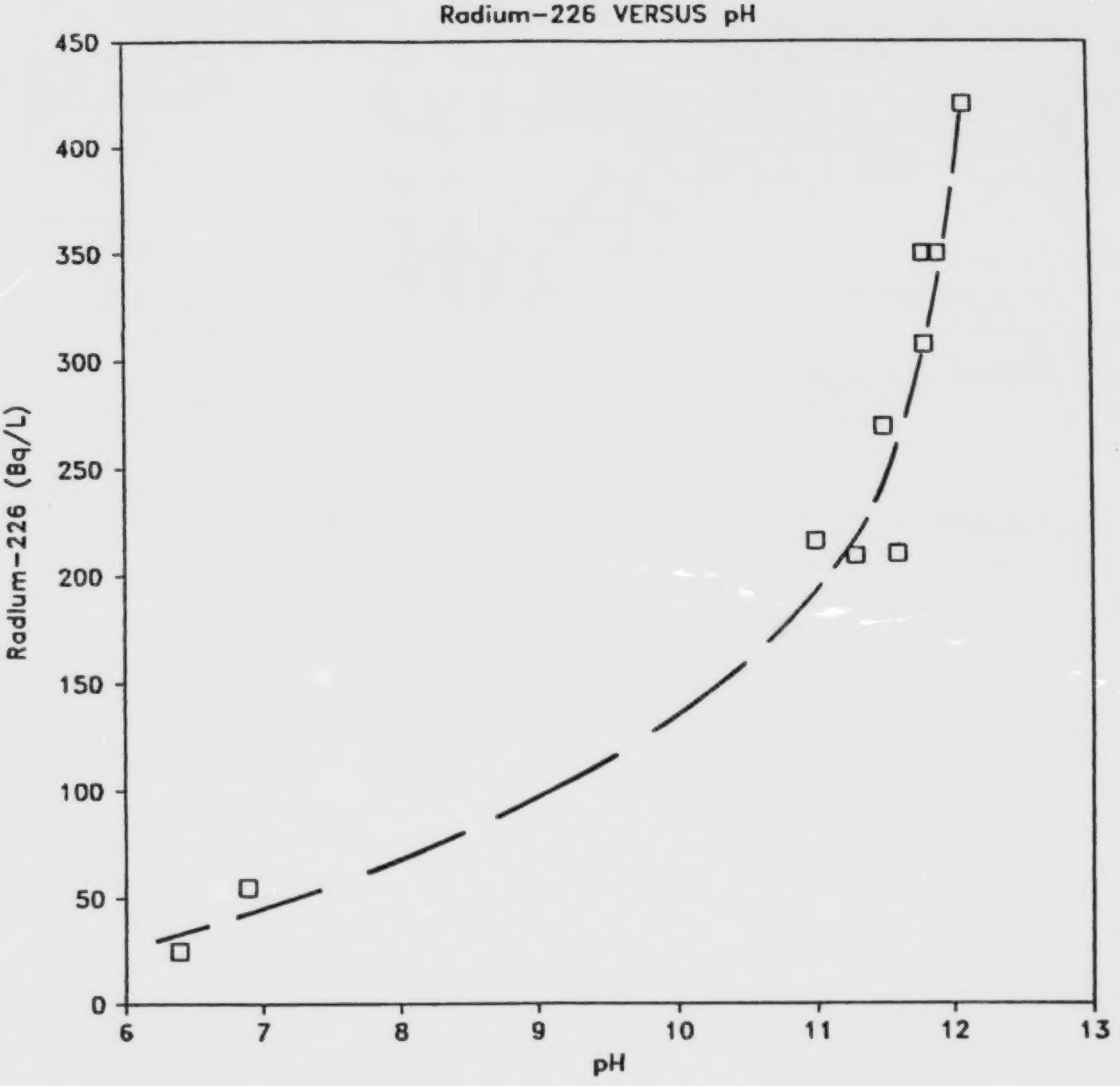

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FIGURE 8.1

MONITORING OF LAYERED URANIUM TAILINGS
PHASE II

POREWATER RADIUM LEVEL VS. pH

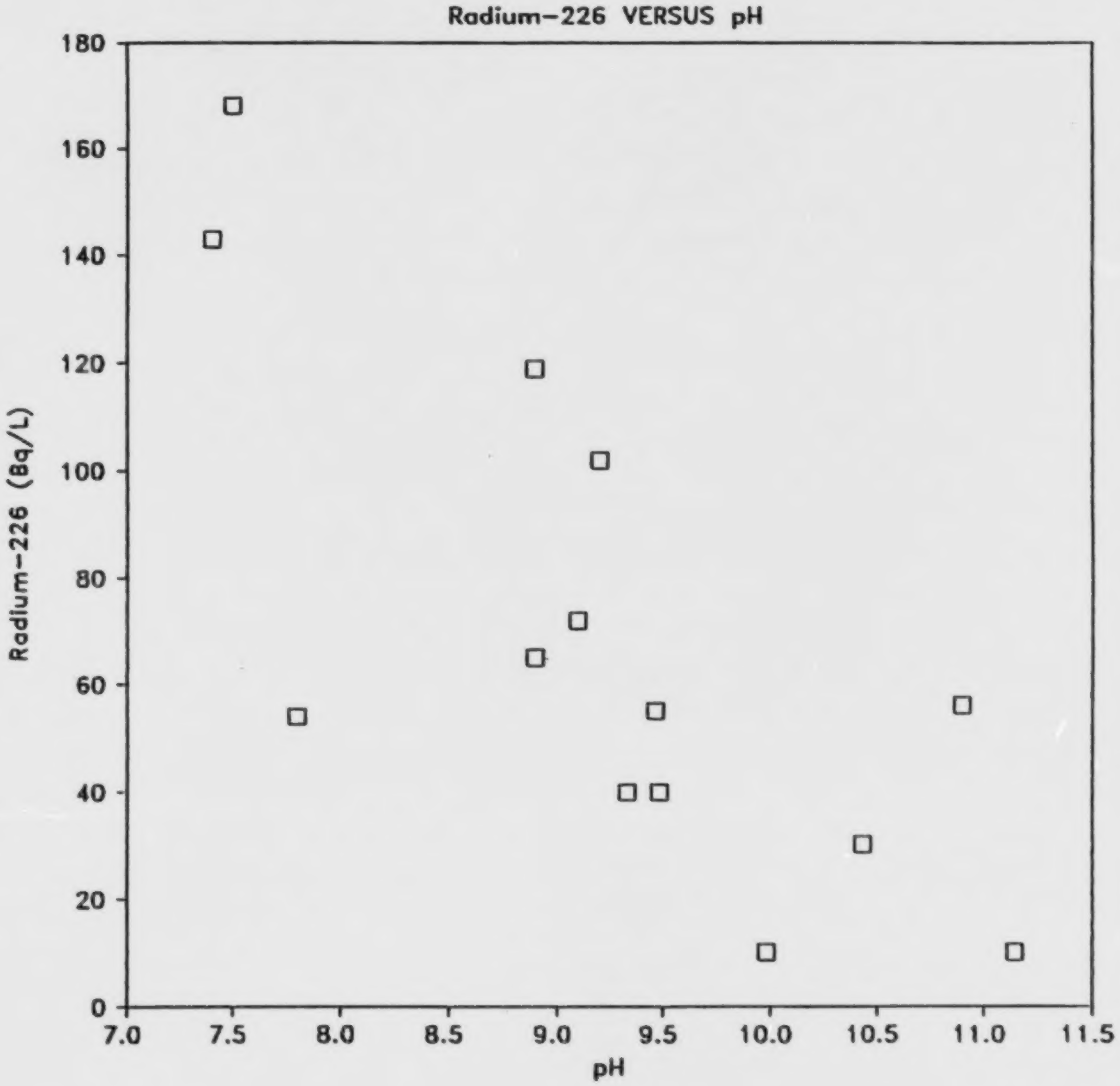

FIGURE 8.2

Of the above mechanisms, adsorption or ion exchange on soil particles is generally regarded as one of the most important factors. Iron, manganese and aluminum oxides and hydroxides have also been found to be important geochemical traps in attenuating contaminant transport.

The most rigorous approach to the evaluation of retardation of chemical species is to apply thermodynamic analysis. The cost of this rigorous thermodynamic approach, however, is very high since one must accurately characterize the mineral and chemical composition of the system in detail to successfully employ this technique. The information requirements of such an approach are far too extensive for this study, therefore, a much simpler approach using a laboratory measured distribution coefficient K_D was employed. The distribution coefficient is defined as the concentration of solute in the adsorbed phase (mass of solute per unit mass of soil) divided by the concentration of solute in the solution phase (mass of solute per unit volume of soil porewater). The K_D value is normally reported in units of mL/g for each contaminant (radioactive and non-radioactive) and represents the partitioning of the contaminant between the solid and solution phases.

For the geochemical modelling study of Key Lake tailings, the prime consideration was to determine the ability of the natural soil to adsorb contaminants from the seepage. It is worth noting that the natural soil already contains background levels of the contaminants that are measured in the porewater.

9.1.1 Materials and Sample Preparation

The objective of the testing program was to obtain an order of magnitude estimate of the retention capabilities of the local natural materials. The detailed methods and procedures for conducting the test work are outlined in Appendix C. Because of the short time frame and preliminary nature of these studies a rapid and inexpensive batch shaker flask procedure was adopted.

Forty litres of seepage water from an existing tailings area were collected, as were representative samples of uncontaminated sand, sandstone, bentonite and till. The seepage water contained residual solids having the characteristics of iron floc. Prior to use, the seepage water was filtered through a 0.45 u membrane filter to remove any residual solids.

The solids (sand, sandstone, till, and till/bentonite) were dried. The sand and the till samples were sieved through an 18-mesh (1 mm) sieve. The -1 mm fraction was used without any further preparation. The sandstone was agitated in a puck and ring pulverizer for five seconds to desegregate the particles prior to passing through the 18-mesh sieve. The -1 mm fraction of the sandstone was used. A fourth solid sample was prepared by mixing the -1 mm till with bentonite to give 3% bentonite content.

9.2 TEST PROCEDURE

Two hundred grams of solid sample were added to 1.8 L of seepage water in heavy walled, acid and distilled water rinsed, Nalgene bottles. When required, the pH of the solution was adjusted to pH = 5.0 with sulphuric acid. Nitrogen from a liquid nitrogen source was flushed into the headspace of each bottle before sealing. The bottles were shaken for 24 or 72 hours, as prescribed, on a mechanical shaker at ambient temperatures. After shaking, the samples were allowed to settle for several hours. The liquid sample was then filtered through a 3 u filter and an aliquot was retained for Ra-226 analysis. The remaining liquid was filtered through a 0.45 u filter prior to analysis. The test schedule and program is detailed in Table 9.1.

9.2.1 Chemisorption of Metals and Distribution Coefficients (K_D)

The chemical characteristics of the substrates (sand, etc.) are given in Table 9.2. The analytical results of the chemisorption studies are given in Table 9.3. Adsorption of metal ions on solid surfaces is known to depend on the equilibrium pH. The seepage water had an initial pH value of 6.3. An initial pH adjustment to 5.0 with sulfuric acid, however had no detectable effect on the pH values when the seepage was shaken with the solids for 24 hours.

Rather, the pH values were independent on the type of solid substrate and ranged from pH = 3.9 to 4.7 in sand, pH = 5.5 to 6.5 in sandstone, pH = 5.0 to 6.4 in till, and pH = 6.3 to pH = 6.6 in till/bentonite suspensions. Usually, a pH decline was observed when the shaking period was extended to 72 hours.

The calculated K_D values for each substrate are provided in Table 9.4.

The geometric mean values and the ranges of the distribution coefficients are shown on Table 9.5. An interesting feature of the results is the relatively high adsorption of metals forming multivalent, anionic, oxo-complexes (AsO_4^{-3}, MoO_4^{-2}) on sand surfaces. Sand is known to be a poor sorption substrate for most metals. Cationic oxo-complexes (UO_2^{+2}), cations (Ca^{+2}, Ra^{+2}, etc.), and neutral hydroxo species ($Th(OH)_4$) are virtually unadsorbed. In sandstone, besides arsenate and molybdate, the sorption of the uranyl (UO_2^{+2}) and the zinc (Zn^{+2}) ions also become significant. Relatively high sorption of radium is observable on till and till/bentonite substrates only. The sorption of other divalent cations (Ni^{+2}, Sr^{+2}, Co^{+2}, Ca^{+2}) and monovalent oxo-ion (MnO_4^{-1}) is virtually nil in any of the solid/seepage water suspensions.

TABLE 9.1

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

TEST SCHEDULE AND PROGRAM

				Analyses						
No.	Soil Type	Initial pH	Shake Time (hr)	pH	Cond.	Ra-226	Th Isotopes	U	As	Plasma Scan
1	sand	A.R.	24	X	X	X	X	X	X	X
2	sand	A.R.	72	X	X	X	-	X	X	X
3	sand	5.0	24	X	X	X	X	X	X	X
4	t/b	A.R.	24	X	X	X	X	X	X	X
5	t/b	A.R.	72	X	X	X	-	X	X	X
6	t/b	5.0	24	X	X	X	-	X	X	X
7	till	A.R.	24	X	X	X	X	X	X	X
8	till	A.R.	72	X	X	X	-	X	X	X
9	till	5.0	24	X	X	X	-	X	X	X
10	sandstone	A.R.	24	X	X	X	X	X	X	X
11	sandstone	A.R.	72	X	X	X	X	X	X	X
12	sandstone	5.0	24	X	X	X	X	X	X	X
13	sandstone	5.0	72	X	X	X	-	X	X	X
14	control	A.R.	24	X	X	X	X	X	X	X

t/b - till bentonite
A.R. - as received
Cond. - conductivity
X - analysis carried out

For preliminary evaluation of contaminant transport, a range of K_D values about the geometric mean has been provided. This range of K_D values is somewhat subjective and based upon the variability in test results obtained.

The K_D results did vary with contact time but the results were somewhat erratic. Some values increased with longer contact times while others decreased.

For comparison the measured K_D values are compared with literature values for As, U, Th and Ra in Table 9.6. As a general rule As, U, and Ra values fall within the range of values reported in the literature. Thorium K_D values are low. This is in part due to the very low levels of thorium in tailings seepage.

The expected best estimate of source concentrations are provided in Table 9.7 along with the suggested range of values for modelling. Also provided for comparison are the measured seepage quality of the test program sample and the range of values measured in porewater during 1985.

TABLE 9.2

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

SUBSTRATE ANALYSES

SAMPLE DESCRIPTION		SAND	SAND-STONE	TILL	TILL/ BENTONITE
Mo	ppm	<1	<1	<1	<1
W	ppm	<10	<10	<10	<10
Zn	ppm	3	1	3	6
P	ppm	60	70	75	80
Pb	ppm	7	3	7	11
Bi	ppm	<2	<2	<2	<2
Cd	ppm	0.5	0.5	0.5	0.5
Co	ppm	<1	<1	<1	<1
Ni	ppm	7	7	9	6
Ba	ppm	40	30	220	15
Fe	%	0.29	0.30	0.38	0.25
Mn	ppm	9	9	19	8
Cr	ppm	155	145	145	130
Mg	%	0.02	0.01	0.06	0.03
V	ppm	6	6	8	9
Al	%	0.47	0.39	0.62	1.19
Be	ppm	<0.5	<0.5	<0.5	<0.5
Ca	%	0.04	0.02	0.05	<0.01
Cu	ppm	<1	<1	<1	<1
Ti	%	0.018	0.031	0.032	0.020
Sr	ppm	56	35	39	73
Na	%	0.14	0.09	0.15	0.01
K	%	0.09	0.06	0.07	0.12
As	ppm	<2	<2	<2	<2
U	ppm	0.6	0.2	0.3	0.5

TABLE 9.3A

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

SCAVENGING STUDY ANALYSES

Sample Description	Mn ppb	Sr ppb	Co ppb	Ca ppm	Na ppm	K ppm	Th230 Bq/L	Th232/228 Bq/L	Ra226 Bq/L
SAND									
72 hours	950	1030	15	525	35	11	-	-	9.9
24 hours	910	940	15	560	36	10	0.26	0.13	10.5
24 hours (PH 5)	950	855	10	530	33	9	0.56	0.11	9.6
Initial	805	880	10	550	35	9	0.66	0.26	16.5
SANDSTONE									
72 hours	1450	1600	5	530	35	11	-	-	5.8
72 hours (PH 5)	1450	1370	10	520	32	10	0.30	0.26	6.1
24 hours	1250	870	10	490	30	9	0.36	0.20	8.4
24 hours (PH 5)	1800	960	15	565	35	11	0.66	0.26	9.6
Initial	805	880	10	550	35	9	0.66	0.26	16.5
TILL									
72 hours	980	970	15	535	36	12	-	-	5.7
24 hours	910	855	15	605	36	11	0.59	0.19	4.1
24 hours (PH 5)	880	855	15	525	33	10	-	-	1.9
Initial	805	880	10	550	35	9	0.66	0.26	16.5
TILL/BENTONITE									
72 hours	1280	1050	10	485	78	12	-	-	0.45
24 hours	730	955	< 5	490	76	11	0.33	0.15	1.8
24 hours (PH 5)	865	880	5	465	71	10	-	-	1.5
Initial	805	880	10	550	35	9	0.66	0.26	16.5
CONTROL									
24 hours	765	805	10	510	35	9	0.69	0.26	17.1
SID								-	12.6

TABLE 9.3B

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

SCAVENGING STUDY ANALYSES (Continued)

Sample Description	PH	Cond	As ppb	U ppb	Ni ppb	Mo ppb	Zn ppb	P ppb
SAND								
72 hours	3.9	2230	10	80	310	40	200	60
24 hours	4.7	2200	4.4	29	280	175	165	55
24 hours (PH 5)	4.3	2200	3.3	60	300	145	150	< 50
Initial	6.3	2100	60	37	250	670	150	< 50
SANDSTONE								
72 hours	6.5	2150	6.2	3	120	290	< 5	60
72 hours (PH 5)	6.3	2140	6.3	6	220	115	5	< 50
24 hours	5.5	2200	4	9	280	85	95	< 50
24 hours (PH 5)	2.8	2900	17	34	300	205	170	80
Initial	6.3	2100	60	37	250	670	150	< 50
TILL								
72 hours	5.0	2150	10	11	380	40	110	60
24 hours	5.9	2200	6.3	6	260	630	< 5	80
24 hours (PH 5)	6.4	2200	5.8	9	320	480	55	75
Initial	6.3	2100	60	37	250	670	150	< 50
TILL/BENTONITE								
72 hours	6.3	2250	1.6	3	290	480	5	80
24 hours	6.9	2300	28	11	160	610	< 5	275
24 hours (PH 5)	6.6	2300	22	4	220	560	< 5	240
Initial	6.3	2100	60	37	240	670	150	< 50
CONTROL								
24 hours	4.4	2200	68	30	230	645	150	50
SID	-	-	2050	1.0	930	-	-	-

Sulphate ion concentration of the seepage water - 1350 ppm. Other elements quantified by ICP analysis were less than the detection limit and showed no variation. These elements and their detection, limits in brackets are as follows:

W(50), Pb(5), Bi(10), Cd(2), Ba(50), Fe(0.5), Cr(50), Mg(0.5), V(5), Al(0.5), Be(2), Cu(5), Ti(0.05).

TABLE 9.4

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

K_D VALUES CALCULATED FROM LABORATORY DATA

(mL/g)

Media Type	Mix Time	As	U	Ni	Mo	Zn	Mn	Sr	Co	Ca	Th 230	Ra 226	Th 228&232
Sand	72	45.0	-4.8*	-1.7	141.8	-2.3	-1.4	-1.3	-3.0	0.4	-	6.0	-
Sand	24	113.7	2.5	-1.0	25.5	-0.8	-1.0	-0.6	-3.0	-2.0	13.8	5.1	9.0
Sand	24	154.6	-3.4	-1.5	32.6	0.0	-1.4	0.3	0.0	0.3	1.6	6.5	12.3
Sandstone	72	78.1	102.0	9.8	11.8	261.0	-4.0	-4.0	9.0	0.3	-	16.6	-
Sandstone	72	76.7	46.5	1.2	43.4	261.0	-4.0	-3.2	0.0	0.5	10.8	15.3	0.0
Sandstone	24	126.0	28.0	-1.0	61.9	5.2	-3.2	0.1	0.0	1.1	7.5	8.7	2.7
Sandstone	24	22.8	0.8	-1.5	20.4	-1.1	-5.0	-0.8	-3.0	-0.2	0.0	6.5	0.0
Till	72	45.0	21.3	-3.1	141.8	3.3	-1.6	-0.8	-3.0	0.3	-	17.1	-
Till	24	76.7	46.5	-0.3	0.6	261.0	-1.0	0.3	-3.0	-0.8	1.1	27.2	3.3
Till	24	84.1	28.0	-2.0	3.6	15.5	-0.8	0.3	-3.0	0.4	-	69.2	-
T/BT	72	328.5	102.0	-1.2	3.6	261.0	-3.3	-1.5	0.0	1.2	-	321.0	-
T/BT	24	10.3	21.3	5.1	0.9	261.0	0.9	-0.7	9.0	1.1	9.0	73.5	6.6
T/BT	24	15.5	74.3	1.2	1.8	261.0	-0.6	0.0	9.0	1.6	-	90.0	-

* negative values indicate that the constituent was leached from the substrate (could also be some evaporation)

TABLE 9.5

KEY LAKE PROJECT

MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

MEAN AND DISTRIBUTION OF THE K_D VALUE FOR VARIOUS DISSOLVED METALS

(mL/g)

Media Type	As	U	Ni	Mo	Zn	Mn	Sr	Co	Ca	Th 230	Th 228 & 232	Ra-226
Filter Blanket	92[1] (46-184)[2]	0[3]	0	49 (25-150)	0	0	0	0	0	5 (1-20)	10 (7-15)	6 (4-9)
Underseal	37 (10-300)	54 (27-108)	2 (0-5)	2 (1-4)	261 (200-300)	0	0	0	1 (0.5-2)	9.0 (0-20)	7 (0-15)	130 (65-300)
Till	66 (33-132)	30 (15-60)	0	7 (1-100)	24 (2-240)	0	0	0	0	1.0 (0-2)	3.0 (0-10)	32 (16-64)
Athabasca Formation	64 (32-128)	18 (1-100)	2 (0-10)	28 (14-56)	25 (0-250)	0	0	0	0.4 (0-1)	5 (0-15)	1 (0-3)	11 (5-20)

1 - approximate geometric mean where applicable

2 - suggested range of K_d values for modelling

3 - 0 value indicates little adsorption or in some cases leaching of the contaminant from the substrate

SECTION 10.0 - HYDROGEOLOGICAL IMPACT

10.1 INTRODUCTION

Seepage which migrates from the bottom of the tailings mass is modified by several complex physical, chemical and biological processes as it is transported through engineered and natural materials. The previous Sections have summarized studies which determined the expected chemical composition of any seepage and the distribution coefficients of contaminants when in contact with various materials. In this Section, the physical mechanisms which influence contaminant concentrations and the attentuation characteristics of the natural materials are examined in order to assess the possible impact on both surface water and groundwater. The analyses incorporate natural hydrogeological parameters from the site, such as the hydraulic conductivities of the various materials and the measured hydraulic gradients within the regional groundwater system. The travel times and probable concentrations for specific elements at the nearest groundwater discharge are also presented.

10.2 NATURAL HYDROGEOLOGICAL CONDITIONS

The major geological units at the site are the lower crystalline basement rock, overlain by sandstone and conglomerate comprising the Athabasca Formation, and overburden materials. The overburden material consists of medium dense to very dense sandy till.

The groundwater table lies within the Athabasca Formation throughout most of the area beneath the storage facility and has not changed significantly since project start-up. The groundwater flows under a gradient of about 0.9% towards Wolf Lake. There are no surface water flows in the general location of the site.

TABLE 9.6

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

COMPARISON OF MEAN VALUES OF LABORATORY K_D RESULTS (mL/g) WITH TYPICAL LITERATURE VALUES

	Laboratory Results (mean)				Literature Values*	
	Sand	Sandstone	Till	Till/Bentonite	Typical Range	Average
Arsenic	92	64	66	37	0-300	-
Uranium	0	18	30	54	5-500	20
Thorium-230	5	5	1	9	50-5000	500
-232	10	1	3	7		
Radium-226	6	11	32	130	5-500	50

*Values for U, Th, and Ra based on data reported in National Research Council, 1983. "A Study of the Isolation System for Geologic Disposal of Radioactive Wastes". Waste Isolation Systems Panel, Board on Radioactive Waste Management, Commission on Physical Sciences, Mathematics, and Resources, Washington.

TABLE 9.7

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

LONG TERM SEEPAGE QUALITY

	Best Estimate Long Term Level	Range Expected for Modelling	Seepage Sample Tested	Range 1985 Porewater Samples
As mg/L	3	2-10	0.06	0.62-13
U mg/L	0.5	0.1-2.0	0.037	< .001-.01
Ni mg/L	3	1-15	0.25	0.085-.560
Mo mg/L	1	0.4-5	0.67	0.58-3.04
Zn mg/L	0.3	0.1-1	0.15	< .005-.05
Th-230 -232 Bq/L	0.5	0.1-2	0.66	0.33-1.09
Ra-226 Bq/L	30	10-100	16.5	53.5-167.6
pH units	6-7.0	6-8.0	6.3	7.5-10.9

The Athabasca Formation is the major aquifer and has an average hydraulic conductivity of 3.0×10^{-6} m/s. A somewhat higher hydraulic conductivity of about 4.6×10^{-5} m/s occurs directly under the tailings facility causing the groundwater flow to concentrate in a north eastern direction.

The hydraulic conductivity of the lower crystalline basement rocks is substantially lower at about 5.6×10^{-7} m/s. The relatively low permeability and small hydraulic gradients restrict groundwater movement so that flow in the basement rock is insignificant.

The unconsolidated sandy till has an average hydraulic conductivity of about 2.8×10^{-6} m/s. The groundwater table is generally within the Athabasca Formation, and the overlying till remains unsaturated.

The baseline groundwater volume flowing under the tailings area has been estimated to be about 280 m^3/day. The average groundwater recharge for till areas is about 45% of the total annual precipitation of 460 mm. Seasonal recharge causes minor fluctuations in the groundwater table which are generally less than 1 metre. This recharge rate has likely been reduced as a result of the tailings facility and a conservative value of 150 m^3/day will be used for contaminant transport modeling.

The various parameters used in developing a simple contaminant transport model are summarized on Figure 10.1.

10.3 CONTAMINANT TRANSPORT

Analytical solutions provide a crude estimate for describing the movement of contaminants through geological materials. The various mechanisms which influence contaminant retardation have been identified in Section 9.1, along with the results of preliminary laboratory tests designed to provide estimates of the distribution coefficients for various metal ions contacted with natural materials.

As previously indicated, the distribution coefficient is a measure of the degree at which contaminant mass is transfered by adsorption or other chemical processes to the solids in the porous medium. This transfer, while flow occurs, retards the rate of advance of the contaminant front.

10.3.1 Retardation of Contaminants

The distribution coefficients described in Section 9 and summarized on Table 9.5 can be used to define retardation factors for the various dissolved metals by means of the following formula:

$$R_d = 1 + \frac{K_D \rho}{n}$$

where R_d is the retardation factor
K_D is the distribution coefficient
ρ is the bulk density of the geologic material
n is the porosity of the geologic material

This relationship has been used to calculate the parameters listed in Table 10.1, which also includes the range of these values.

10.3.2 Contaminant Migration Rates

Natural uncontaminated groundwater flow velocities are generally determined by application of the following formula:

$$\bar{V} = \frac{ki}{n}$$

TABLE 10.1

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

MEAN AND DISTRIBUTION OF RETARDATION FACTORS

FORMATION	As	U	Ni	Mo	Zn	Ca	Th 230	Th 228 232	Ra-226
Filter Blanket	448 (224-895)	1	1	239 (122-730)	1	1	25 (6-98)	50 (35-74)	30 (20-45)
Underseal	235 (64-1901)	343 (172-685)	14 (1-33)	14 (7-26)	1654 (1268-1901)	7 (4-14)	58 (1-128)	45 (1-96)	824 (413-1901)
Till	322 (161-642)	147 (74-642)	1	35 (6-487)	118 (11-1167)	1	6 (1-11)	16 (1-50)	156 (25-312)
Athabasca Formation	1473 (737-2945)	415 (24-2301)	47 (1-231)	645 (323-1289)	576 (1-5751)	10 (1-24)	116 (1-346)	24 (1-70)	254 (116-461)

NOTE: Numbers in brackets represent the possible range of values. Mn, Sr, and Co are unretarded ($R_D = 1$).

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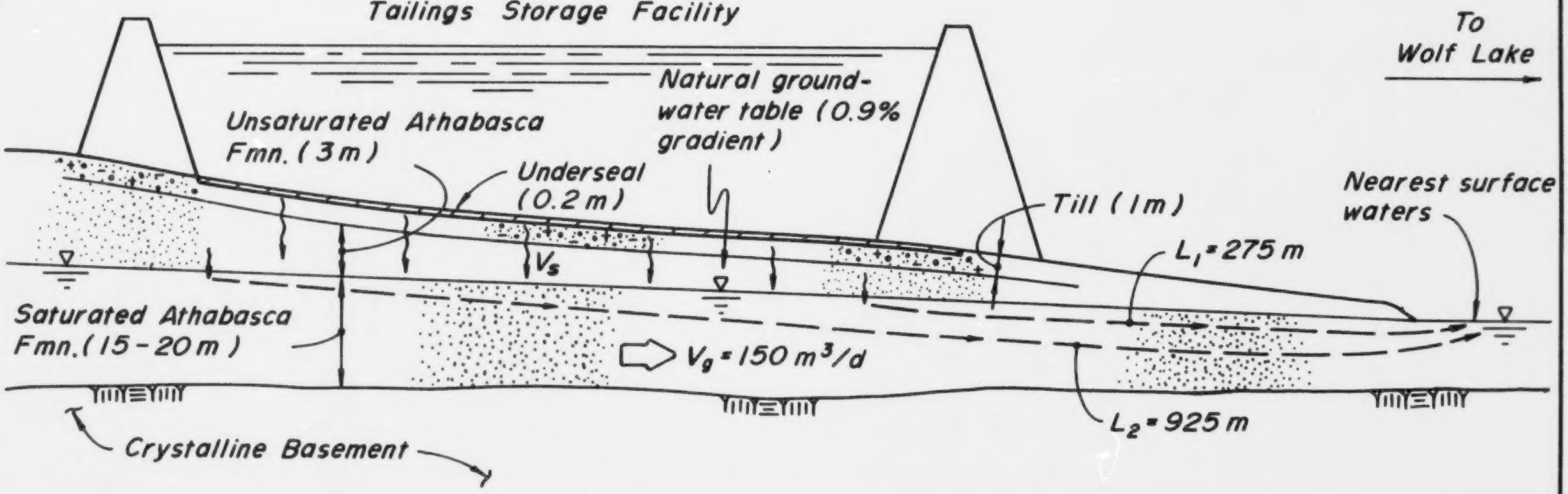
PHASE II

SUMMARY OF PHYSICAL PARAMETERS USED IN CONTAMINANT TRANSPORT MODEL


Tailings Storage Facility
To Wolf Lake
Natural ground-water table (0.9% gradient)
Unsaturated Athabasca Fmn. (3 m)
Underseal (0.2 m)
V_s
Till (1 m)
Nearest surface waters
$L_1 = 275$ m
Saturated Athabasca Fmn. (15 - 20 m)
$V_g = 150$ m^3/d
$L_2 = 925$ m
Crystalline Basement

MATERIAL	POROSITY	HYDRAULIC GRADIENT	HYDRAULIC CONDUCTIVITY - k (m/s)	AVER. LINEAR VELOCITY - $\bar{V}$ (m/day)
Underseal	0.30	3.1	1.0×10^{-9}	8.9×10^{-4}
Till	0.35	1.0	2.8×10^{-6}	0.7
Athabasca Formation	0.10	1.0 (Vert. seepage)	4.6×10^{-5}	40.0
		0.009 (Groundwater)	4.6×10^{-5}	0.36
Crystalline Basement	0.01	0.009	3.1×10^{-7}	0.024

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FIGURE 10.1

where $\overline{V}$ is the average linear velocity
k is the hydraulic conductivity
i is the hydraulic gradient
n is the volumetric porosity contributing to groundwater flow.

This relationship was used to calculate the flow velocities presented on Figure 10.1.

Previous test work summarized on Table 10.2 indicates that the total porosity of samples collected from the Athabasca Formation averaged 10.1% and the permeability to air averaged 6.2 millidarcy, which translates to a hydraulic conductivity of 4.5×10^{-5} m/s for water at 5°C. The calculated hydraulic conductivity correlates well with values derived from field tests at the tailings storage facility. This observation, coupled with the high porosity values indicate that groundwater flow is dominated by the porosity of the rock mass and not by fracture characteristics.

Groundwater or leachate flows in the unsaturated zone may be substantially different, since partial saturation influences the average linear velocity. Although the unsaturated hydraulic conductivity is less, the hydraulic gradient increases due to suction pressures, and the porosity through which flow occurs is reduced. These factors tend to compensate somewhat, but it is difficult to accurately determine the overall effect on flow velocities. For simplicity, saturated flow conditions are assumed for regions above the water table.

The migration velocities of specific contaminants may be substantially different than the average flow velocity of uncontaminated water. The following relationship accounts for the retardation of the various contaminants:

$$U_c = \frac{\bar{V}}{R_d}$$

where U_c = Migration velocity of the contaminant plume where C/Co = 0.5, (C = actual concentration, C_o = initial concentration)

$\bar{V}$ = Average linear velocity of the groundwater

R_d = Retardation factor

The migration velocities of several dissolved metals have been calculated and are included in Table 10.3. The best estimate values are based on the expected long term concentrations of the contaminants (Table 9.7) and the mean value of the distribution coefficients (Table 9.5). The possible range of migration velocities is also included. It is evident that attenuation is an important factor in reducing migration velocities of some contaminants, whereas unretarded contaminants travel at the groundwater velocity.

10.3.3 Travel Times

The travel times of the various dissolved metals are summarized in Tables 10.4 and 10.5. Average seepage lengths are also tabulated. The minimum travel distance within the saturated Athabasca Formation is the shortest flow path from the eastern boundary of the facility to the nearest surface water, which is adjacent to Wolf Lake. The maximum travel distance is the seepage path from the western boundary of the facility to the same discharge point as shown schematically on Figure 10.1. The actual seepage path lengths will vary between these limiting values.

TABLE 10.2

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

RESULTS OF CORE TESTS CARRIED OUT ON DRILL CORES FROM THE ATHABASCA FORMATION

Hole No.	Depth Interval (Feet)		Permeability to Air (millidarcy)	Total Porosity (%)
120	119	(ss)	9.34	8.5
12	75	(ss)	3.15	13.0
126	81	(ss)	37.50	11.1
552	212	(ss)	0.39	10.6
70	101	(ss)	3.34	13.3
123	42	(ss)	25.00	15.0
	58	(cg)	43.60	10.5
	68	(ss)	128.00	13.4
	80	(ss)	131.00	17.5
	90	(ss)	29.90	11.4
	106	(cg)	0.72	2.8
	123	(cg)	0.26	4.6
	126	(cg)	12.00	6.6
	137	(cg)	0.07	3.3
			Geometric Mean: 6.20	Arithmetic Mean: 10.1%

(ss = sandstone; cg - conglomerate)

Source: CORE LABORATORIES - CANADA Limited, Report dated May 25, 1976.

Table 10.4 indicates that groundwater below the tailings facility will require 2.1 years to initially reach the first groundwater discharge. Prior to reaching the groundwater table, seepage effluent must travel through the underseal, and unsaturated zone. It is estimated that unretarded solutes will take about 0.6 years to pass through the underseal, after which they will rapidly (about 1.5 days) reach the groundwater flow system. The mean travel time for unretarded solute to surface water is therefore 2.7 years.

However, the movement of attenuated contaminants such as As, U, Mo, Zn and Ra-226 is significantly slower. Over 1000 years are required for a significant concentration of the contaminants to reach the nearest groundwater discharge. The travel times are based on the transport of a hypothetical contaminant concentration of one half that of the initial concentration leaving the tailings. The actual concentration level of contaminants arriving at the nearest surface waters will be significantly less due to mechanical dispersion or dilution with natural groundwater, as discussed in Section 10.3.5.

Predicted travel times for the various ions are summarized on Table 10.5.

10.3.4 Expected Seepage Rates

The monitoring programs have provided additional insight into the factors which influence seepage rates. Previous analyses indicated that the tailings were the controlling factor for seepage out of the facility. However, it is now evident that seepage flows through the tailings are higher than originally anticipated. Thus a greater reliance is placed on the underseal and underdrainage systems for restricting seepage losses.

TABLE 10.3

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

MIGRATION VELOCITIES FOR VARIOUS DISSOLVED METALS

FORMATION	SEEPAGE VELOCITY (m/day)	MIGRATION VELOCITY - U_c (m/day)								
		As	U	Ni	Mo	Zn	Ca	Th 230	Th 228 232	Ra-226
Underseal	8.9×10^{-4}	3.8×10^{-6} (14-0.47)	2.6×10^{-6} (5.2-1.3)	6.4×10^{-5} (89-2.7)	6.4×10^{-5} (13-3.4)	5.4×10^{-7} (7.0-4.6)	1.3×10^{-4} (2.2-0.6)	1.5×10^{-5} (89-0.7)	2.0×10^{-5} (89-0.9)	1.1×10^{-6} (2.2-0.5)
Unsaturated Till	0.7	2.1×10^{-3} (4.3-1.1)	4.7×10^{-3} (9.3-1.1)	0.7	2.0×10^{-2} (12-.1)	5.9×10^{-3} (63-.6)	0.7	0.1 (0.7-.06)	4.3×10^{-2} (7-1.4)	4.4×10^{-3} (28-2.2)
Unsaturated Athabasca Formation	40	2.7×10^{-2} (5.4-1.4)	9.6×10^{-2} (166-1.7)	0.85 (40-0.17)	.062 (.12-.031)	.069 (40-.007)	4 (40-1.7)	0.34 (40-0.12)	1.7 (40-.57)	0.16 (0.34-.087)
Saturated Athabasca Formation	0.36	2.4×10^{-4} (4.9-1.2)	8.7×10^{-4} (150-1.6)	7.7×10^{-3} (360-1.6)	5.6×10^{-4} (11-2.8)	6.3×10^{-4} (3600-0.6)	0.04 (36-.02)	3.1×10^{-3} (360-1.0)	1.5×10^{-2} (36-.5)	1.4×10^{-3} (3.1-0.8)

NOTE: Numbers in brackets represent the possible range of values.
Mn, Sr and Co are unretarded ($U_c = \bar{V}$).

APPENDIX AII

ADDITIONS TO STATEMENT OF WORK AND CONTRACT AMENDMENTS

MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

During the second last field visit it was observed that the freezing of the tailings surface over night (September 27 to 30th) resulted in significant changes in consolidation characteristics of the tailings. Since these changes appear to be very beneficial to the long-term behaviour of such tailings, it is necessary that the effect of freeze-thaw be quantified.

New Work:

1. In the field, conduct standard settling tests on representative tailings.

2. Subject representative tailings to freezing conditions at the site to partially freeze the sample. Conduct settling tests on thawed material and compare with standard.

3. Obtain samples of decant water from frozen and unfrozen slurries and submit for representative chemical analyses.

4. Compare particle morphology of frozen and unfrozen tailings by optical methods.

5. Record tests photographically.

TABLE 10.4

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

TRAVEL TIMES FOR VARIOUS DISSOLVED METALS

FORMATION	SEEPAGE LENGTH (m)	TRAVEL TIME									Time Unit
		As	U	Ni	Mo	Zn	Ca	Th 230	Th 228, 232	Ra-226	
Underseal	0.2	140 (39-1200)	210 (110-420)	8.6 (0.6-20)	8.6 (4.2-16)	1000 (780-1200)	4.2 (2.5-9.1)	37 (0.6-78)	27 (0.6-61)	500 (250-1100)	Years
Unsaturated Till	1.0	480 (230-910)	210 (110-910)	1.4	50 (8-1000)	170 (16-1700)	1.4	10 (1.4-17)	23 (14-71)	230 (36-460)	Days
Unsaturated Athabasca Formation	3.0	110 (56-210)	31 (1.8-180)	3.5 (0.08-18)	48 (25-97)	43 (0.08-430)	0.8 (0.08-1.8)	8.8 (0.08-25)	1.8 (0.08-5)	19 (8.8-34)	Days
Saturated Athabasca Formation	275 (min)	3100 (1500-6300)	870 (50-4700)	99 (2.1-470)	1300 (870-2700)	1200 (2.1-13,000)	19 (2.1-38)	240 (2.1-750)	50 (2.1-150)	540 (240-940)	Years
	925 (max)	11,000 (5200-21,000)	2900 (170-16,000)	330 (7.0-1600)	4500 (2300-9100)	4000 (7-42,000)	63 (7-130)	820 (7-2500)	170 (7-510)	1,800 (820-3200)	Years

Note: Mn, Sr and Co are unretarded with travel times equal to the minimum values for Ni, Th_{230}, Th_{228} and Th_{232}.

APPENDIX B

DATA TABLES

TABLE 10.5

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

SUMMARY OF TRAVEL TIMES FOR SHORTEST DISTANCE TO SURFACE WATER

	Mean (Year)	Range (Year)	
		Minimum	Maximum
Unretarded ions	2.7	-	-
As	3300	1600	7,400
U	1100	160	1,100
Ni	110	2.7	490
Mo	1400	870	2,700
Zn	2200	790	14,000
Ca	23	2.7	47
Th 230	280	2.7	830
Th 228, 232	78	2.7	210
Ra 226	1000	490	1,700

A worst case seepage estimate based on an average underseal permeability of 1 x 10^{-9} m/s, an average hydraulic gradient of 3.0 over the entire underseal (30.5 hectares) indicates a flow of 80 m^3/day. However, construction records indicate that the actual permeability of the underseal is likely less than 5 x 10^{-10} m/sec. Also, recent site observations indicate that the actual seepage area is restricted to less than one quarter of the underseal except during short periods when frozen tailings are thawing. Therefore, the most likely rate that leachates are seeping out of the facility is probably less than 10 m^3/day. The following estimates of potential seepage through the underseal summarize present conditions:

	Total Seepage (m^3/day)
Worst Case (Most Pessimistic)	80
Best Estimate (Most Likely)	10

In future years, when the tailings are thicker and more compressed, it is likely that the tailings material will become a major barrier to moisture movement. However, the underseal and underdrainage system will ensure minimal seepage from the tailings facility regardless of any improvements in tailings permeability characteristics.

10.3.5 Seepage Impacts

The potential impact of contaminants on water quality down gradient of the tailings storage facility can be estimated after considering contaminant attenuation mechanisms, travel distances, travel times and the degree of mixing with uncontaminated groundwater. It is impossible to accurately quantify the degree of mechanical mixing which occurs as leachates are transported in the groundwater system. For a simplistic analysis, it is assumed that complete mixing of leachates with natural groundwater will result prior to discharge at the nearest surface waters. The resulting concentration of completely mixed water is described by the following relationship:

$$C_m = (C_s V_s + C_g V_g) / (V_g + V_s)$$

where C_m is the contaminant concentration of completely mixed seepage and groundwater.
C_s is the contaminant concentration in seepage prior to mixing.
C_g is the contaminant concentration in the groundwater prior to mixing.
V_s is the volumetric flow rate of seepage.
V_g is the volumetric flow rate of groundwater.

This relationship is summarized in Figure 10.2, which indicates that the contaminant concentrations of completely mixed seepage and groundwater will likely be about 6.3% of the initial seepage concentration for the initial best estimate flow rates indicated. For the estimated worst case flow rate occurring in the first year of operation, the concentration of the mixture could be about 34.8% of the initial seepage concentration.

Figure 10.2 can also be used to assess the influence of different seepage rates, groundwater flow or initial concentrations on the final concentration of the combined flows.

The contaminant concentration in the completely mixed groundwater will also be reduced by the attentuation mechanisms previously discussed. Also, radioactive contaminants such as Ra-226 will undergo radioactive decay during transport. Figure 10.3 illustrates the reduction in Ra-226 levels due to radioactive decay and dilution, assuming a seepage rate of 10 m^3/day.

SECTION 11.0 - CONSIDERATIONS FOR FUTURE WORK

The results of Phase I and Phase II studies have highlighted several major difficulties with the continuous monitoring of a constantly varying tailings facility. The difficulties were in part due to the problems of adapting previously untried instrumentation to the unusual and specific requirements of the project. Instrument failure, data loss, and operator error severely impacted on the ability to achieve the project objectives. With necessary time and budgetary constraints a significant part of the "learning curve" was included within the data collection period and consequently failed instrumentation and lost or distorted data were not effectively replaced.

Field observations resulted in a greater awareness of the significant role played by freeze-thaw cycles on such factors as water recovery from the tailings, in-situ tailings density and moisture content and consequently on the overall storage capacity of the facility.

Considerations for future work include the following:

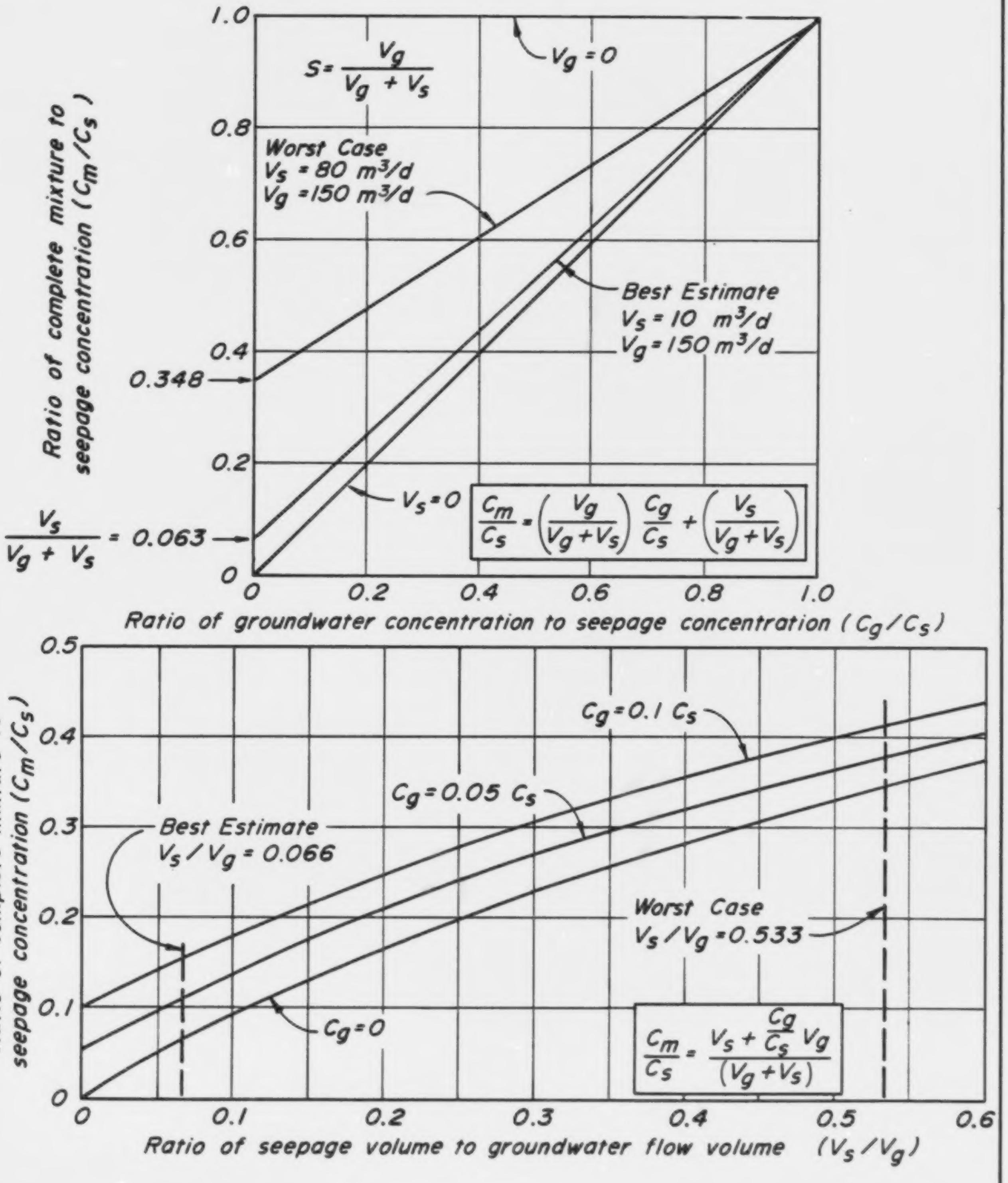
(i) Development of an economical and trouble free instrumentation package for continuously monitoring a range of meteorological and geotechnical instruments and flow meters. Due consideration must be given to factors such as susceptibility to freezing temperatures, temperature compensation of sensors, low power requirements, fail safe provisions in data logger, protection from rodent damage and lightning strikes, ease of installation maintenance and repair on site.

(ii) Development of a reliable and portable moisture/density gauge for very cold conditions, that is easy to calibrate and check, that is not subject to mechanical damage due to differential thermal expansion of metal components under extreme cold conditions

NCI-763

MONITORING OF LAYERED URANIUM TAILINGS
PHASE II

DILUTION OF SEEPAGE IN GROUNDWATER



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CONSULTING ENGINEERS

FIGURE 10.2

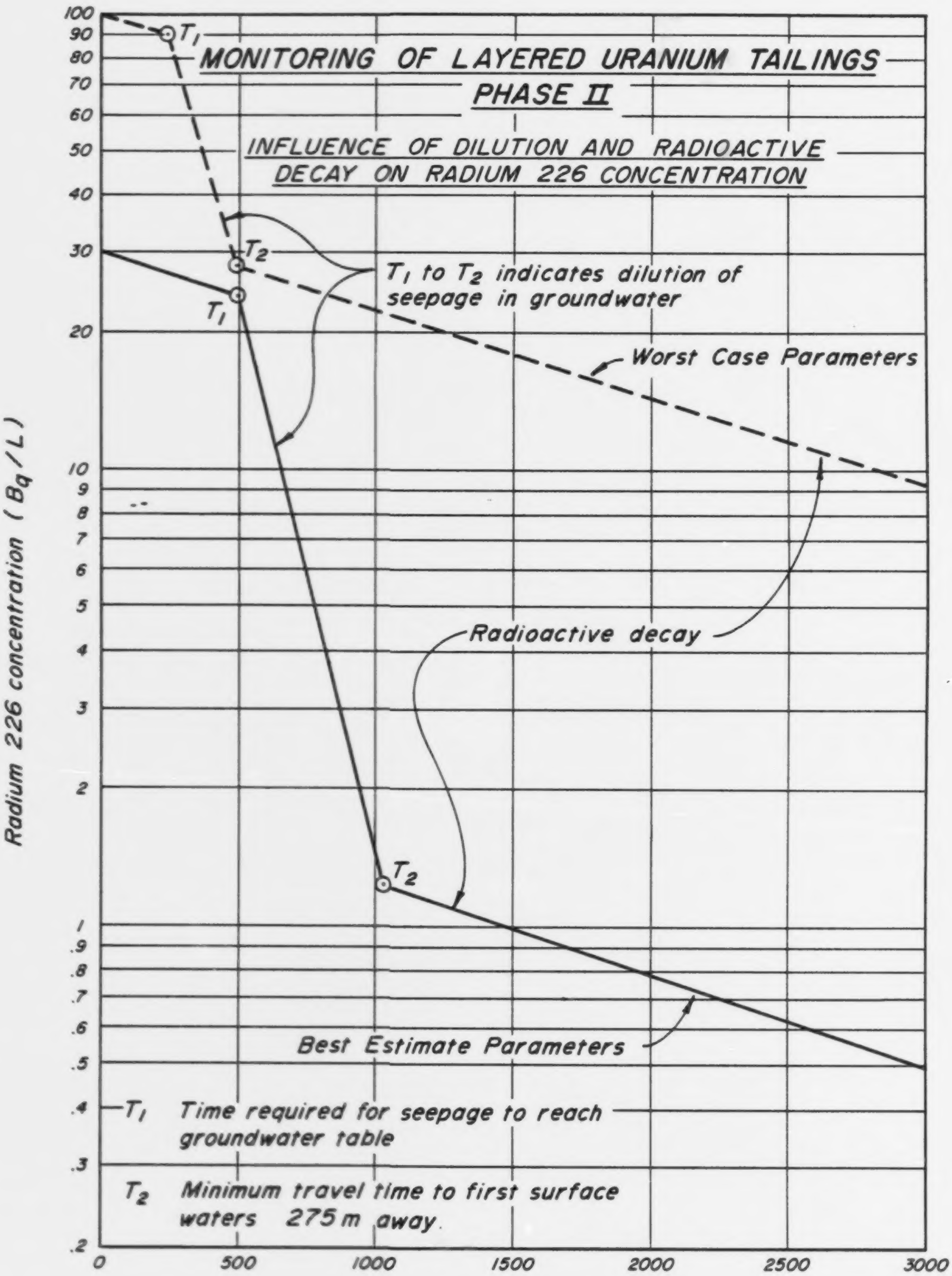

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FIGURE 10.3

and that is able to be serviced or repaired, on site, using simple modular components.

(iii) Carry out a detailed investigation of tailings behaviour under freeze-thaw conditions including such factors as:

- Grain size and distribution.
- Initial solids contents and densities.
- Mineral/chemical nature of the tailings slurries.
- Nature of tailings deposition and provision for water removal.
- Depth and mode of freezing and thawing.
- Collapse and consolidation of previously frozen tailings under additional loading.
- Permeability of previously frozen tailings before and after collapse and consolidation.
- Relative effects of winter freeze versus night/day freeze-thaw cycling.
- Orientation of freezing front.
- Number of freeze-thaw cycles on water recovery.
- Changes in the distribution of chemical species between solid and ice (liquid) phases.

With a greater understanding of the effect of freeze-thaw cycles on tailings material and their subsequent consolidation, improved monitoring instrumentation and continuing operation of a tailings system in a systematic manner a more reliable estimation may be made of the tailings facility water balance and ultimate storage capacity.

APPENDIX A

TERMS OF REFERENCE
AI - ORIGINAL STATEMENT OF WORK
AII - ADDITIONS TO STATEMENT OF WORK
AND CONTRACT AMENDMENTS

APPENDIX AI

TERMS OF REFERENCE
ORIGINAL STATEMENT OF WORK

MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

BACKGROUND:

Phase I was completed October 1984 and March 1985. Field measurements and tests were done under winter conditions, which were unusually severe. Access to the tailings surface had to be delayed until freeze up because of unexpected conditions. Physical and chemical laboratory tests had been completed and the results used as bases for chemical and seepage/-consolidation modelling. A major objective of Phase II will be to complement winter observations with summer predictions made in Phase I. A second major objective will be to extend geochemical modelling into the specific geologic material barriers specific to the site.

The specific work elements are:

1. Reactive field data logging systems at Site A, making necessary corrections to malfunctions encountered in Phase I. Seepage collection sampling will be based on a simple trouble-free system that collects a proportional sample between field visits. Special emphasis is required for evaporation and precipitation as it relates to facility water balance.

2. Undertake at least 4 evenly-spaced field visits between May and November 1985 to:

   (a) collect water and core samples;

   (b) extract accumulated data;

   (c) record field observations at both test sites and overall facility.

3. Obtain tailings cores from 2 east-west profiles to determine physical and chemical characteristics as per Phase I specifications. At least 4 locations on each profile. In Phase I work, poor load-bearing capacity of the tailings surface was experienced, so field judgements re safety and choice of sampling sites are required.

4. Conduct identification of tailings solids with special emphasis on qualitative and quantitative determination of status of nickel, arsenic and radium.

5. Conduct thermogravimetric analyses of solids (4 east-west locations) determine hydration characteristics of the tailings. Determine specific gravity of solids.

6. Using field-collected seepage water, conduct laboratory tests to determine interaction of seepage water with appropriate geologic materials representative of the site.

7. Analyse field and laboratory data, relative to overall facility. Special emphasis is required on tailings consolidation, water movement and balance, water chemistry and effect of winter conditions.

Special considerations for this Work.

The Key Lake tailings management facility (TMF) is an active operational site and field conditions may require the work be altered, suspended or cancelled. The impact of the work on the Key Lake operation will be minimized.

The test facilities will be removed from the site and decontaminated before freeze-up in 1985. It is intended that the instrument shed will be of no salvageable value and the instrumentation be delivered to the Crown (Elliot Lake).

Upon completion of Phase II work and acceptance of draft report by the Scientific Authority, a one-half day seminar will be presented in Saskatoon to interested parties.

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TABLE B1

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II
MONTHLY DATA SUMMARY - AUGUST 1985

	channel #2			channel #15			#11	#12	#1	#14	#16
DAY	AIR TEMPERATURE (deg C)			AIR TEMPERATURE (deg C)			PYRAN (W/m2/day)	PRECIP (mm)	FLOW (litres)	HMDTY (%)	WIN RUN (km/dy
	av	max	min	av	max	min	total	total	total	av	
1	#	#	#	#	#	#	#	#	#	#	#
2	#	#	#	#	#	#	#	#	#	#	#
3	#	#	#	#	#	#	#	#	#	#	#
4	#	#	#	#	#	#	#	#	#	#	#
5	#	#	#	#	#	#	#	#	#	#	#
6	#	#	#	#	#	#	#	#	#	#	#
7	#	#	#	#	#	#	#	#	#	#	#
8	#	#	#	#	#	#	#	#	#	#	#
9	#	#	#	#	#	#	#	#	#	#	#
10	#	#	#	#	#	#	#	#	#	#	#
11	#	#	#	#	#	#	#	#	#	#	#
12	#	#	#	#	#	#	#	#	#	#	#
13	#	#	#	#	#	#	#	#	#	#	#
14	#	#	#	#	#	#	#	#	#	#	#
15	#	#	#	#	#	#	#	#	#	#	#
16	#	#	#	#	#	#	#	#	#	#	#
17	#	#	#	#	#	#	#	#	#	#	#
18	#	#	#	#	#	#	#	#	#	#	#
19	#	#	#	#	#	#	#	#	#	#	#
20	#	#	#	#	#	#	#	#	#	#	#
21	#	#	#	#	#	#	#	#	#	#	#
22	#	#	#	#	#	#	#	#	#	#	#
23	#	#	#	#	#	#	#	#	#	#	#
24	#	#	#	#	#	#	#	#	#	#	#
25	#	#	#	#	#	#	#	#	#	#	#
26	7.0	9.7	4.2	7.2	9.5	4.7	15704	0.5	0	44.6	#
27	9.9	15.1	5.8	10.3	15.0	6.4	20816	0.0	0	47.2	#
28	9.5	14.9	4.6	9.9	15.0	5.2	19992	0.0	0	47.2	#
29	13.7	18.0	8.1	14.1	18.6	8.2	20718	0.0	0	47.9	#
30	11.0	16.6	5.2	11.3	16.7	5.9	19528	0.0	0	46.0	#
31	10.1	16.1	5.5	10.4	15.6	6.0	20958	0.0	0	46.6	#

#........NO DATA COLLECTED FOR THIS DATE
*........SENSOR MALFUNCTIONING

NOTES....

RESULTS ARE DAILY AVERAGE OR TOTAL OF AVAILABLE DATA WITH TYPICA SAMPLING FREQUENCY OF 12 SCANS DAILY BASED ON 8AM TO 8AM DAY.

03-06-1986

TABLE B2

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II
MONTHLY DATA SUMMARY - SEPTEMBER 1985

	channel #2			channel #15			#11	#12	#1	#14	#16
DAY	AIR TEMPERATURE (deg C)			AIR TEMPERATURE (deg C)			PYRAN (W/m2/day)	PRECIP (mm)	FLOW (litres)	HMDTY (%)	WIN RUN
	av	max	min	av	max	min	total	total	total	av	(km/dy
1	10.6	16.2	5.5	11.0	16.2	5.9	21590	0.5	0	46.5	#
2	11.3	16.1	7.7	11.6	16.2	7.8	19700	0.3	0	46.2	#
3	5.6	11.1	0.3	5.9	11.0	0.5	18556	0.0	0	46.7	#
4	8.0	11.9	1.1	8.1	12.1	1.2	19998	0.0	0	48.8	#
5	4.0	7.9	1.2	4,3	8.6	1.4	14064	3.5	0	45.8	#
6	3.7	8.2	0.5	4.2	8.5	1.3	18422	0.0	0	46.8	#
7	3.8	6.2	1.7	4.4	6.9	2.3	18070	0.0	0	46.1	#
8	4.8	8.7	1.6	5.3	8.9	2.4	18196	0.0	0	46.6	#
9	8.5	15.2	2.8	9.0	15.4	3.1	19880	0.0	0	47.9	#
10	10.2	15.0	4.6	10.3	14.9	4.6	19778	0.0	0	48.3	#
11	13.6	19.1	6.9	13.7	19.4	6.9	19590	0.0	0	47.9	#
12	13.7	18.6	8.4	13.9	18.6	8.7	18136	0.0	0	47.3	#
13	13.3	16.2	8.0	13.4	16.3	8.2	15472	0.0	60	46.8	#
14	14.3	20.5	7.8	14.6	20.5	8.3	18898	0.0	610	48.1	#
15	12.7	16.7	8.3	12.9	16.9	8.3	18558	0.0	1030	46.8	#
16	9.6	12.1	3.8	9.9	12.3	4.2	15662	0.0	1210	45.5	#
17	1.6	5.2	-1.0	1.8	5.4	-0.7	16818	0.0	1220	45.2	#
18	-0.3	1.3	-2.3	0.2	1.6	-2.0	16454	0.0	1290	45.8	#
19	1.0	4.3	-3.1	1.5	4.7	-2.5	17510	0.0	1380	46.1	#
20	5.5	8.1	1.0	5.7	8.2	1.1	16186	0.0	1420	45.5	#
21	4.3	7.1	0.5	4.7	7.6	0.9	13298	0.0	1440	44.8	#
22	-0.3	1.9	-2.4	0.0	2.2	-2.2	16668	0.0	1510	45.0	#
23	-0.4	3.0	-3.1	-0.0	2.8	-2.7	16494	0.0	1620	45.5	#
24	-1.0	3.6	-5.0	-0.6	4.0	-4.6	16502	0.0	1640	45.9	#
25	2.3	7.0	-4.4	2.6	7.4	-4.2	16410	0.0	1690	45.9	#
26	-0.8	1.7	-2.9	-0.5	2.2	-2.6	13306	0.0	1610	45.4	#
27	#	#	#	#	#	#	#	#	#	#	#
28	#	#	#	#	#	#	#	#	#	#	#
29	#	#	#	#	#	#	#	#	#	#	#
30	7.0	14.5	2.0	7.4	15.1	2.4	16588	0.0	1490	47.7	#

#........NO DATA COLLECTED FOR THIS DATE
*........SENSOR MALFUNCTIONING

NOTES....

RESULTS ARE DAILY AVERAGE OR TOTAL OF AVAILABLE DATA WITH TYPICA SAMPLING FREQUENCY OF 12 SCANS DAILY BASED ON 8AM TO 8AM DAY.

03-06-1986

TABLE B3

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II
MONTHLY DATA SUMMARY - OCTOBER 1985

	channel #2			channel #15			#11	#12	#1	#14	#16
DAY	AIR TEMPERATURE (deg C)			AIR TEMPERATURE (deg C)			PYRAN (W/m2/day)	PRECIP (mm)	FLOW (litres)	HMDTY (%)	WIN RUN
	av	max	min	av	max	min	total	total	total	av	(km/dy
1	5.5	10.2	1.9	6.1	11.3	2.3	14962	0.0	1540	46.5	#
2	6.1	13.0	0.2	6.7	13.7	0.8	15324	1.0	1450	46.7	#
3	1.3	4.6	-1.2	1.8	5.0	-0.8	13350	0.0	1360	46.0	#
4	-0.8	1.3	-2.3	-0.2	1.8	-1.7	13894	0.0	1360	45.9	#
5	-3.0	-0.2	-5.0	-2.6	0.1	-4.4	14122	0.0	1240	45.8	#
6	-5.3	-4.0	-7.1	-4.7	-3.4	-6.4	10386	0.0	1120	46.6	#
7	-5.0	-1.5	-7.6	-4.3	-0.7	-6.7	15872	0.0	1190	46.9	#
8	-4.1	1.2	-8.3	-3.6	2.8	-8.2	16112	0.0	1220	47.7	#
9	-1.3	0.2	-5.4	-1.2	0.3	-5.6	16128	0.0	1210	46.7	#
10	1.0	2.3	-0.6	1.5	2.9	0.0	12972	0.0	1100	45.5	#
11	3.3	5.7	-0.6	3.6	6.3	-0.3	14548	0.0	1160	45.6	#
12	-1.0	2.2	-3.7	-0.6	2.5	-3.3	7846	0.0	1310	45.5	#
13	-4.7	-3.4	-6.7	-4.3	-3.0	-6.3	13634	0.0	1240	45.5	#
14	-6.5	-3.0	-9.2	-5.9	-2.3	-8.6	13134	0.0	1090	46.1	#
15	-5.0	-3.5	-9.2	-4.6	-3.1	-8.8	12120	0.0	990	46.2	#
16	-2.8	-0.1	-4.6	-2.8	-0.1	-4.6	13906	0.0	970	45.5	#
17	-1.3	0.9	-4.6	-1.1	1.3	-4.5	10324	0.0	910	45.5	#
18	-0.4	3.2	-4.5	0.1	3.3	-4.1	14868	0.0	820	45.7	#
19	2.3	5.5	-3.3	2.5	5.7	-3.1	14510	0.0	860	45.6	#
20	2.4	9.1	-1.6	2.9	9.3	-0.9	14476	0.0	960	46.4	#
21	4.6	7.0	0.3	4.8	7.1	0.5	11940	0.0	1070	46.1	#
22	3.5	7.4	-1.0	3.9	7.6	-0.6	11686	0.0	1080	46.1	#
23	-2.1	-0.3	-3.9	-1.8	0.0	-3.5	9310	0.0	1030	46.2	#
24	-3.9	-2.5	-5.6	-3.4	-2.0	-5.1	11984	0.0	950	46.7	#
25	-3.7	-1.6	-6.0	-3.5	-1.4	-5.6	8878	0.0	850	45.7	#
26	-5.9	-4.1	-7.4	-5.6	-3.3	-7.2	11080	0.0	630	44.8	#
27	-4.3	-1.9	-6.6	-6.0	-3.8	-7.6	9516	0.0	620	14.0	#
28	-3.9	-0.3	-9.5	-3.8	0.6	-9.2	5245	0.0	560	43.6	#
29	#	#	#	#	#	#	#	#	#	#	#
30	#	#	#	#	#	#	#	#	#	#	#
31	#	#	#	#	#	#	#	#	#	#	#

#........NO DATA COLLECTED FOR THIS DATE
*........SENSOR MALFUNCTIONING

NOTES....

RESULTS ARE DAILY AVERAGE OR TOTAL OF AVAILABLE DATA WITH TYPICA SAMPLING FREQUENCY OF 12 SCANS DAILY BASED ON 8AM TO 8AM DAY.

03-06-1986

Knight & Piesold Ltd

FILE #...KLTAIL01

TABLE B4

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS – PHASE II
MONTHLY DATA SUMMARY – AUGUST 1985

DAY	channel #13 TAILINGS TEMP (deg C)			channel #3 TAILINGS TEMP (deg C)			channel #4 TAILINGS TEMP (deg C)			ch #5	ch #6	ch #7	ch #8	ch #9	ch #10
										pore water pressure in tailings					
	av	max	min	av	max	min	av	max	min	(mm H2O)	(mm H2O)	(mm H2O)	(mm H2O)	(mm H2O)	(mm H2O)
1	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
2	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
3	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
4	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
5	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
6	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
7	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
8	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
9	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
10	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
11	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
12	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
13	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
14	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
15	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
16	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
17	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
18	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
19	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
20	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
21	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
22	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
23	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
24	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
25	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
26	7.0	10.3	3.4	11.0	11.2	10.9	6.9	7.0	6.9	-80.2	30.0	-585.4	-494.7	631.3	509.1
27	11.9	18.8	5.4	10.8	11.0	10.7	7.0	7.0	6.9	-40.3	10.3	-597.1	-575.5	680.2	571.1
28	11.2	19.3	2.3	10.6	10.7	10.4	7.0	7.0	6.9	-51.3	12.0	-622.3	-569.4	697.1	556.7
29	15.4	24.4	10.5	10.3	10.4	10.2	7.0	7.1	6.9	-37.1	5.5	-581.8	-470.0	726.7	451.0
30	11.4	19.5	4.9	10.1	10.2	10.0	7.0	7.1	7.0	-94.3	-23.3	-547.0	-401.6	678.3	390.9
31	12.3	22.5	4.5	10.0	10.1	10.0	7.0	7.1	7.0	-98.6	-5.0	-533.3	-465.9	669.2	465.6

#........NO DATA COLLECTED FOR THIS DATE
*........SENSOR MALFUNCTIONING

NOTES....

RESULTS ARE DAILY AVERAGE OR TOTAL OF AVAILABLE DATA WITH TYPICA
SAMPLING FREQUENCY OF 12 SCANS DAILY BASED ON 8AM TO 8AM DAY.

03-06-1986

TABLE B5

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II
MONTHLY DATA SUMMARY - SEPTEMBER 1985

DAY	channel #13 TAILINGS TEMP (deg C)			channel #3 TAILINGS TEMP (deg C)			channel #4 TAILINGS TEMP (deg C)			ch #5	ch #6	ch #7	ch #8	ch #9	ch #10
										pore water pressure in tailings					
-	av	max	min	av	max	min	av	max	min	(mm H2O)	(mm H2O)	(mm H2O)	(mm H2O)	(mm H2O)	(mm H2O)
1	11.7	22.1	4.6	10.0	10.0	9.9	7.0	7.1	7.0	-117.2	-6.5	-576.9	-503.3	659.4	490.5
2	12.2	18.4	8.1	9.9	10.0	9.7	7.0	7.1	7.0	-129.6	-12.0	-557.1	-445.2	680.6	424.1
3	6.3	17.7	-1.3	9.8	9.8	9.7	7.1	7.2	7.0	-168.2	-4.3	-564.4	-490.7	647.4	492.5
4	8.7	14.8	1.2	9.6	9.7	9.4	7.1	7.1	7.1	-164.9	18.2	-564.9	-465.8	663.6	451.0
5	3.8	7.9	0.9	9.3	9.5	9.2	7.1	7.2	7.1	-203.3	9.6	-539.8	-449.2	643.2	451.0
6	5.0	13.4	-0.2	9.0	9.2	8.9	7.1	7.2	7.1	-186.2	44.4	-580.3	-587.8	683.2	595.9
7	4.3	8.8	1.5	8.7	8.9	8.5	7.1	7.2	7.1	-211.1	42.2	-708.6	-697.4	687.8	695.1
8	4.6	10.8	0.7	8.4	8.5	8.2	7.1	7.2	7.1	-219.8	48.3	-758.8	-697.7	702.8	684.9
9	11.5	23.3	1.7	8.1	8.3	8.0	7.1	7.2	7.1	-208.2	32.8	-727.8	-664.6	742.7	647.7
10	11.3	19.0	4.9	7.9	8.0	7.9	7.1	7.2	7.1	-223.3	47.2	-740.6	-650.3	735.7	639.6
11	14.8	22.6	9.0	7.8	7.9	7.8	7.1	7.1	7.0	-190.3	40.1	-682.4	-606.7	774.0	596.0
12	14.5	22.0	7.9	8.6	10.9	7.8	7.1	7.1	7.0	-128.0	349.2	-581.2	-641.8	896.2	620.8
13	13.7	17.6	8.9	8.7	8.9	8.6	7.1	7.2	7.0	7.2	956.9	-447.7	-577.6	1213.3	591.9
14	15.6	23.3	7.4	8.8	9.0	8.7	7.1	7.2	7.1	352.1	1000.0	-436.1	-471.7	1333.3	527.7
15	13.8	20.0	10.0	9.1	9.2	9.0	7.1	7.1	7.0	579.7	1040.4	-466.8	-399.3	1272.3	447.0
16	12.6	20.5	6.7	9.4	9.5	9.3	7.1	7.2	7.1	782.7	1179.7	-311.2	-243.8	1415.5	329.0
17	4.7	9.0	1.8	9.5	9.6	9.5	7.1	7.2	7.1	746.4	1192.7	-376.4	-402.5	1364.3	565.0
18	3.6	7.0	1.6	9.7	9.8	9.6	7.1	7.2	7.1	796.6	1230.7	-337.0	-371.4	1412.4	759.7
19	3.9	7.0	2.1	9.7	9.8	9.7	7.1	7.2	7.0	879.2	1247.3	-305.6	-319.3	1453.8	740.9
20	5.5	7.4	2.6	9.7	9.8	9.7	7.1	7.2	7.1	922.7	1233.9	-310.2	-337.0	1423.5	614.6
21	6.3	8.3	3.8	9.6	9.6	9.5	7.1	7.2	7.1	937.1	1225.2	-266.0	-311.9	1440.6	600.1
22	5.6	6.7	4.7	9.4	9.5	9.3	7.1	7.2	7.1	970.4	1310.8	-221.3	-260.5	1501.5	738.8
23	6.9	8.5	4.4	9.3	9.4	9.2	7.2	7.2	7.1	1074.2	1375.8	-139.6	-197.5	1567.3	713.8
24	6.5	7.3	5.3	9.1	9.2	9.0	7.2	7.2	7.1	1096.8	1381.6	-118.8	-176.9	1583.2	695.3
25	4.6	5.1	4.2	9.0	9.2	9.0	7.2	7.3	7.2	1139.3	1379.8	-116.0	-175.9	1567.3	612.4
26	4.2	4.7	3.4	9.0	9.0	8.9	7.2	7.3	7.2	1033.3	1324.6	-181.9	-254.6	1512.3	707.8
27	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
28	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
29	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
30	3.7	5.4	1.9	8.3	8.4	8.2	7.3	7.4	7.1	1103.0	1193.8	-116.1	-234.7	1537.0	612.5

#........NO DATA COLLECTED FOR THIS DATE
*........SENSOR MALFUNCTIONING

NOTES....

RESULTS ARE DAILY AVERAGE OR TOTAL OF AVAILABLE DATA WITH TYPICA
SAMPLING FREQUENCY OF 12 SCANS DAILY BASED ON 8AM TO 8AM DAY.

03-06-1986

Knight & Piesold Ltd FILE #...KLTAIL1

TABLE B6

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II
MONTHLY DATA SUMMARY - OCTOBER 1985

	channel #13			channel #3			channel #4			ch #5	ch #6	ch #7	ch #8	ch #9	ch #10
DAY	TAILINGS TEMP			TAILINGS TEMP			TAILINGS TEMP				pore water pressure in tailings				
	(deg C)			(deg C)			(deg C)			(mm H2O)	(mm H2O)	(mm H2O)	(mm H2O)	(mm H2O)	(mm H2O)
-	av	max	min	av	max	min	av	max	min						
1	4.2	5.1	2.7	8.1	8.2	8.0	7.3	7.3	7.1	1085.0	1145.0	-120.8	-256.5	1500.3	494.7
2	4.9	7.2	2.8	8.0	8.1	7.9	7.2	7.3	7.2	1019.6	1079.8	-158.2	-319.8	1435.0	507.0
3	2.7	4.6	0.9	7.8	7.9	7.7	7.3	7.3	7.2	921.5	1027.9	-233.5	-386.5	1389.8	656.0
4	0.8	1.6	-0.1	7.6	7.7	7.6	7.2	7.3	7.1	897.9	1020.8	-280.6	-413.1	1345.9	720.1
5	-0.6	0.1	-1.2	7.5	7.6	7.4	7.2	7.3	7.1	882.4	1018.1	-287.4	-430.0	1323.3	699.4
6	-0.5	-0.3	-1.1	7.4	7.4	7.3	7.2	7.3	7.2	781.5	898.8	-430.2	-559.8	1164.0	745.1
7	-0.3	0.0	-0.8	7.2	7.3	7.1	7.2	7.3	7.1	702.9	787.0	-530.8	-643.2	1052.7	757.5
8	-1.1	-0.1	-3.6	7.0	7.2	6.9	7.2	7.2	7.1	683.5	725.3	-579.8	-659.9	1009.1	743.0
9	-1.2	-0.6	-2.9	6.9	7.0	6.8	7.2	7.2	7.1	660.3	684.6	-659.5	-708.7	922.7	604.3
10	-0.2	0.0	-0.6	6.7	6.7	6.6	7.1	7.2	7.1	597.1	577.5	-715.0	-752.8	852.4	537.9
11	0.8	1.6	0.0	6.5	6.6	6.4	7.0	7.1	7.0	667.1	754.9	-477.6	-634.1	1121.7	531.8
12	0.2	1.0	-0.1	6.4	6.4	6.3	7.1	7.1	7.0	825.8	1060.9	-170.8	-432.2	1474.8	515.3
13	-0.5	-0.1	-1.1	6.2	6.3	6.1	7.0	7.1	7.0	687.1	835.6	-450.6	-602.2	1164.0	654.0
14	-1.0	-0.2	-1.7	6.0	6.1	5.9	7.0	7.1	7.0	552.9	602.4	-708.4	-770.4	877.6	720.2
15	-0.8	-0.3	-2.0	5.8	5.9	5.8	7.0	7.0	7.0	474.8	507.8	-794.0	-859.9	732.6	738.8
16	-1.0	-0.7	-2.2	5.7	5.8	5.7	7.0	7.0	6.9	432.8	455.8	-756.9	-906.3	659.7	672.5
17	-0.4	-0.2	-0.8	5.5	5.6	5.4	6.9	7.0	6.8	402.9	399.3	-703.8	-928.6	637.6	598.2
18	-0.3	-0.2	-0.7	5.4	5.5	5.3	6.9	6.9	6.9	363.2	320.9	-654.6	-945.8	624.2	682.8
19	-0.1	0.3	-0.8	5.3	5.3	5.2	6.9	6.9	6.8	393.6	356.1	-673.8	-923.8	625.7	645.8
20	0.1	1.2	-0.6	5.1	5.2	5.1	6.8	6.8	6.8	492.8	494.8	-634.3	-752.5	968.0	614.6
21	1.1	2.2	-0.5	5.0	5.1	4.9	6.8	6.8	6.7	596.1	598.1	-566.6	-707.3	905.8	505.0
22	1.5	4.3	-0.2	4.9	5.0	4.9	6.7	6.8	6.7	656.8	709.8	-421.3	-622.8	1014.4	376.4
23	-0.6	-0.1	-0.9	4.8	4.9	4.8	6.7	6.7	6.7	599.0	763.4	-425.7	-650.9	1119.3	534.0
24	-1.1	-0.4	-2.4	4.7	4.8	4.7	6.7	6.7	6.6	487.4	569.3	-661.2	-804.3	841.7	649.8
25	-1.0	-0.4	-2.7	4.7	4.8	4.6	6.7	6.8	6.6	257.8	462.5	-835.3	-1042.9	504.3	805.2
26	-0.3	-0.1	-0.4	4.6	4.7	4.6	6.7	6.8	6.7	74.2	350.5	-910.2	-1227.1	321.9	1020.6
27	-0.3	-0.2	-0.4	4.5	4.6	4.4	6.6	6.7	6.5	91.7	327.4	-915.6	-1230.9	285.4	983.3
28	-0.2	-0.1	-0.4	4.5	4.6	4.4	6.6	6.7	6.5	71.4	279.3	-891.3	-1241.4	280.3	902.6
29	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
30	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#
31	#	#	#	#	#	#	#	#	#	#	#	#	#	#	#

#........NO DATA COLLECTED FOR THIS DATE
*........SENSOR MALFUNCTIONING

NOTES....

RESULTS ARE DAILY AVERAGE OR TOTAL OF AVAILABLE DATA WITH TYPIC
SAMPLING FREQUENCY OF 12 SCANS DAILY BASED ON 8AM TO 8AM DAY.

03-06-198

TABLE B7

Knight & Piesold Ltd
KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
MOISTURE & DENSITY CALCULATED FROM CORE SAMPLES

site A...cores

assumed solids specific gravity = 2.64 gm/cc

SAMPLE #	TARE (gm)	TOTWET (gm)	TOTDRY (gm)	WET (gm)	DRY (gm)	WATER (gm)	CALCVOL (cc)	SOLID (%)	WATER (%)	M/C (%)	PORE (m3/m3)	DRYDEN (t/m3)	BLKDEN (t/m3)
bulk	10.0	1423.8	975.0	1413.8	965.0	448.8	814.3	68.3	31.7	46.5	0.551	1.185	1.736
AVERAGE.......				1413.8	965.0	448.8	814.3	68.3	31.7	46.5	0.551	1.185	1.736
1-1 top	10.0	129.6	52.4	119.6	42.4	77.2	93.3	35.5	64.5	182.1	0.828	0.455	1.282
1-2	10.0	153.3	56.6	143.3	46.6	96.7	114.4	32.5	67.5	207.5	0.846	0.408	1.253
1-3	10.0	155.4	70.1	145.4	60.1	85.3	108.1	41.3	58.7	141.9	0.789	0.556	1.345
1-4 bot	10.0	153.7	71.5	143.7	61.5	82.2	105.5	42.8	57.2	133.7	0.779	0.583	1.362
AVERAGE.......				552.0	210.6	341.4	421.2	38.2	61.8	162.1	0.811	0.500	1.311
2-1 top	10.0	236.0	117.0	226.0	107.0	119.0	159.5	47.3	52.7	111.2	0.746	0.671	1.417
2-2 bot	10.0	153.6	85.4	143.6	75.4	68.2	96.8	52.5	47.5	90.5	0.705	0.779	1.484
AVERAGE.......				369.6	182.4	187.2	256.3	49.4	50.6	102.6	0.730	0.712	1.442

NOTES......

ALL CALCULATIONS ASSUME THAT SAMPLES ARE COMPLETELY SATURATED
CALCVOL = WATER VOL + (DRY WGT SOLIDS/SPECIFIC GRAVITY SOLIDS)
PORE = WATER LOSS/((WATER LOSS + (DRY WGT/SOLIDS S.G.))
DRYDEN = DRY WEIGHT/((WATER LOSS + (DRY WGT/SOLIDS S.G.))
BLKDEN = WET WEIGHT/((WATER LOSS + (DRY WGT/SOLIDS S.G.))

FILE NAME.. corejune.2
DATE....... 02-28-1986

TABLE B8

Knight & Piesold Ltd
KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
MOISTURE & DENSITY CALCULATED FROM CORE SAMPLES

cores.....keylake....july 12/13/14

assumed solids specific gravity = 2.64 gm/cc

SAMPLE #	TARE (gm)	TOTWET (gm)	TOTDRY (gm)	NET (gm)	DRY (gm)	WATER (gm)	CALCVOL (cc)	SOLID (%)	WATER (%)	M/C (%)	PORE (m3/m3)	DRYDEN (t/m3)	BLKDEN (t/m3)
1-1	20.0	861.2	429.3	841.2	409.3	431.9	586.9	48.7	51.3	105.5	0.736	0.697	1.433
AVERAGE.......				841.2	409.3	431.9	586.9	48.7	51.3	105.5	0.736	0.697	1.433
2-1	20.0	1654.4	1162.5	1634.4	1142.5	491.9	924.7	69.9	30.1	43.1	0.532	1.236	1.768
2-2	20.0	2976.3	1685.0	2956.3	1665.0	1291.3	1922.0	56.3	43.7	77.6	0.672	0.866	1.538
AVERAGE.......				4590.7	2807.5	1783.2	2846.6	61.2	38.8	63.5	0.626	0.986	1.613
2-2	9.0	447.7	242.1	438.7	233.1	205.6	293.9	53.1	46.9	88.2	0.700	0.793	1.493
2-2	9.0	504.4	184.4	495.4	175.4	320.0	386.4	35.4	64.6	182.4	0.828	0.454	1.282
AVERAGE.......				934.1	408.5	525.6	680.3	43.7	56.3	128.7	0.773	0.600	1.373
2-1	9.0	333.1	108.0	324.1	99.0	225.1	262.6	30.5	69.5	227.4	0.857	0.377	1.234
2-1	9.0	299.0	107.0	290.0	98.0	192.0	229.1	33.8	66.2	195.9	0.838	0.428	1.266
AVERAGE.......				614.1	197.0	417.1	491.7	32.1	67.9	211.7	0.848	0.401	1.249
2-3	9.0	669.4	240.8	660.4	231.8	428.6	516.4	35.1	64.9	184.9	0.830	0.449	1.279
2-3	9.0	334.4	134.0	325.4	125.0	200.4	247.7	38.4	61.6	160.3	0.809	0.505	1.313
AVERAGE.......				985.8	356.8	629.0	764.2	36.2	63.8	176.3	0.823	0.467	1.290
2-4	9.0	368.4	119.8	359.4	110.8	248.6	290.6	30.8	69.2	224.4	0.856	0.381	1.237
2-4	9.0	484.0	265.7	475.0	256.7	218.3	315.5	54.0	46.0	85.0	0.692	0.814	1.505
AVERAGE.......				834.4	367.5	466.9	606.1	44.0	56.0	127.0	0.770	0.606	1.377
A1-1 TOP	14.2	843.6	597.2	829.4	583.0	246.4	467.2	70.3	29.7	42.3	0.527	1.248	1.775
A1-2	20.0	1074.7	783.2	1054.7	763.2	291.5	580.6	72.4	27.6	38.2	0.502	1.315	1.817
A1-3	20.0	1110.1	664.6	1090.1	644.6	445.5	689.7	59.1	40.9	69.1	0.646	0.935	1.581
A1-4	20.0	1049.9	802.1	1029.9	782.1	247.8	544.1	75.9	24.1	31.7	0.455	1.438	1.893
AVERAGE.......				4004.1	2772.9	1231.2	2281.5	69.3	30.7	44.4	0.54[illegible]	1.215	1.755
A2-1 TOP	9.0	524.7	209.3	515.7	200.3	315.4	391.3	38.8	61.2	157.5	0.805	0.512	1.318
A2-2	20.0	1008.6	309.2	988.6	289.2	699.4	808.9	29.3	70.7	241.8	0.865	0.358	1.222
A2-3	20.0	1277.9	505.8	1257.9	485.8	772.1	956.1	38.6	61.4	158.9	0.808	0.508	1.316
A2-4	20.0	662.3	218.1	642.3	198.1	444.2	519.2	30.8	69.2	224.2	0.855	0.382	1.237
A2-5	9.0	442.5	142.1	433.5	133.1	300.4	350.8	30.7	69.3	225.7	0.856	0.379	1.236
AVERAGE.......				3838.0	1306.5	2531.5	3026.4	34.0	66.0	193.8	0.836	0.432	1.268
A3-1 TOP	9.0	272.6	104.1	263.6	95.1	168.5	204.5	36.1	63.9	177.2	0.824	0.465	1.289
A3-2	9.0	315.6	153.9	306.6	144.9	161.7	216.6	47.3	52.7	111.6	0.747	0.669	1.416
A3-3	9.0	290.4	107.3	281.4	98.3	183.1	220.3	34.9	65.1	186.2	0.831	0.446	1.277
A3-4	14.2	554.2	196.5	540.0	182.3	357.7	426.8	33.8	66.2	196.2	0.838	0.427	1.265
AVERAGE.......				1391.6	520.7	870.9	1068.2	37.4	62.6	167.3	0.815	0.487	1.303
A4-1 TOP	20.0	480.7	298.0	460.7	278.0	182.7	288.0	60.3	39.7	65.7	0.634	0.965	1.600
A4-2	9.0	254.3	112.5	245.3	103.5	141.8	181.0	42.2	57.8	137.0	0.783	0.572	1.355
A4-3	9.0	526.7	212.3	517.7	203.3	314.4	391.4	39.3	60.7	154.6	0.803	0.519	1.323

A4-4	14.2	432.4	197.5	418.2	183.3	234.9	304.4	43.8	56.2	128.2	0.772	0.602	1.374
AVERAGE.......				1641.9	768.1	873.8	1164.8	46.8	53.2	117.3	0.750	0.659	1.410
S1-1 TOP	14.2	820.2	364.7	806.0	350.5	455.5	588.2	43.5	56.5	129.9	0.774	0.596	1.370
S1-2	9.0	365.7	134.4	356.7	125.4	231.3	278.8	35.1	64.9	184.5	0.830	0.450	1.279
S1-3	9.0	381.8	120.9	372.8	111.9	260.9	303.3	30.0	70.0	233.3	0.860	0.369	1.229
S1-4	20.0	431.6	163.7	411.6	143.7	267.9	322.3	34.9	65.1	186.4	0.831	0.446	1.277
AVERAGE.......				1947.1	731.5	1215.6	1492.7	37.6	62.4	166.2	0.814	0.490	1.304
S2-1	20.0	211.0	125.7	191.0	105.7	85.3	125.3	55.3	44.7	80.7	0.681	0.843	1.524
S2-2	14.2	431.0	197.8	416.8	183.6	233.2	302.9	44.0	56.0	127.0	0.770	0.606	1.377
S2-3	20.0	321.2	125.8	301.2	105.8	195.4	235.5	35.1	64.9	184.6	0.830	0.450	1.279
S2-4	20.0	457.4	156.3	437.4	136.3	301.1	352.7	31.2	68.8	221.0	0.854	0.386	1.240
AVERAGE.......				1346.4	531.4	815.0	1016.3	39.5	60.5	153.4	0.802	0.523	1.325

NOTES......

ALL CALCULATIONS ASSUME THAT SAMPLES ARE COMPLETELY SATURATED

CALCVOL = WATER VOL + (DRY WGT SOLIDS/SPECIFIC GRAVITY SOLIDS)
PORE   = WATER LOSS/((WATER LOSS + (DRY WGT/SOLIDS S.G.))
DRYDEN = DRY WEIGHT/((WATER LOSS + (DRY WGT/SOLIDS S.G.))
BLKDEN = WET WEIGHT/((WATER LOSS + (DRY WGT/SOLIDS S.G.))

FILE NAME.. CORESULT.13
DATE....... 03-03-1986

Knight & Piesold Ltd
KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
MOISTURE & DENSITY CALCULATED FROM CORE SAMPLES

TABLE B9

site A ......core samples...aug 24 1985...dried at 60 then 105 C

assumed solids specific gravity = 2.64 gm/cc

SAMPLE #	TARE (gm)	TOTWET (gm)	TOTDRY (gm)	WET (gm)	DRY (gm)	WATER (gm)	CALCVOL (cc)	SOLID (%)	WATER (%)	W/C (%)	PORE (m3/m3)	DRYDEN (t/m3)	BLKDEN (t/m3)
1-1 top	10.4	192.0	106.5	181.6	96.1	85.5	121.9	52.9	47.1	89.0	0.701	0.788	1.490
2-2	10.4	284.4	155.3	274.0	144.9	129.1	184.0	52.9	47.1	89.1	0.702	0.788	1.489
1-3	19.1	320.6	150.5	301.5	131.4	170.1	219.9	43.6	56.4	129.5	0.774	0.598	1.371
1-4	19.1	707.1	263.5	688.0	244.4	443.6	536.2	35.5	64.5	181.5	0.827	0.456	1.283
AVERAGE.......				1445.1	616.8	828.3	1061.9	42.7	57.3	134.3	0.780	0.581	1.361
1-1 top	10.4	192.0	97.7	181.6	87.3	94.3	127.4	48.1	51.9	108.0	0.740	0.685	1.426
1-2	10.4	284.4	144.6	274.0	134.2	139.8	190.6	49.0	51.0	104.2	0.733	0.704	1.437
1-3	19.1	320.6	139.5	301.5	120.4	181.1	226.7	39.9	60.1	150.4	0.799	0.531	1.330
1-4	19.1	707.1	218.5	688.0	199.4	488.6	564.1	29.0	71.0	245.0	0.866	0.353	1.220
AVERAGE.......				1445.1	541.3	903.8	1108.8	37.5	62.5	167.0	0.815	0.488	1.303
1-1 top	10.4	192.0	97.5	181.6	87.1	94.5	127.5	48.0	52.0	108.5	0.741	0.683	1.424
1-2	10.4	284.4	143.6	274.0	133.2	140.8	191.3	48.6	51.4	105.7	0.736	0.696	1.433
1-3	19.1	320.6	138.0	301.5	118.9	182.6	227.7	39.4	60.6	153.6	0.802	0.522	1.324
1-4	19.1	707.1	216.4	688.0	197.3	490.7	565.4	28.7	71.3	248.7	0.868	0.349	1.217
AVERAGE.......				1445.1	536.5	908.6	1111.8	37.1	62.9	169.4	0.817	0.483	1.300
2-1 top	10.4	247.9	160.9	237.5	150.5	87.0	144.0	63.4	36.6	57.8	0.604	1.045	1.649
2-2	19.1	313.4	138.7	294.3	119.6	174.7	220.0	40.6	59.4	146.1	0.794	0.544	1.338
2-3	19.1	401.7	166.1	382.6	147.0	235.6	291.3	38.4	61.6	160.3	0.809	0.505	1.314
2-4	19.1	330.6	119.8	311.5	100.7	210.8	248.9	32.3	67.7	209.3	0.847	0.405	1.251
AVERAGE.......				1225.9	517.8	708.1	904.2	42.2	57.8	136.8	0.783	0.573	1.356
2-1 top	10.4	247.9	151.3	237.5	140.9	96.6	150.0	59.3	40.7	68.6	0.644	0.940	1.584
2-2	19.1	313.4	125.3	294.3	106.2	188.1	228.3	36.1	63.9	177.1	0.824	0.465	1.289
2-3	19.1	401.7	144.9	382.6	125.8	256.8	304.5	32.9	67.1	204.1	0.843	0.413	1.257
2-4	19.1	330.6	105.2	311.5	86.1	225.4	258.0	27.6	72.4	261.8	0.874	0.334	1.207
AVERAGE.......				1225.9	459.0	766.9	940.8	37.4	62.6	167.1	0.815	0.488	1.303
2-1 top	10.4	247.9	150.8	237.5	140.4	97.1	150.3	59.1	40.9	69.2	0.646	0.934	1.580
2-2	19.1	313.4	124.4	294.3	105.3	189.0	228.9	35.8	64.2	179.5	0.826	0.460	1.286
2-3	19.1	401.7	143.4	382.6	124.3	258.3	305.4	32.5	67.5	207.8	0.846	0.407	1.253
2-4	19.1	330.6	104.5	311.5	85.4	226.1	258.4	27.4	72.6	264.8	0.875	0.330	1.205
AVERAGE.......				1225.9	455.4	770.5	943.0	37.1	62.9	169.2	0.817	0.483	1.300

NOTES......

ALL CALCULATIONS ASSUME THAT SAMPLES ARE COMPLETELY SATURATED
CALCVOL = WATER VOL + (DRY WGT SOLIDS/SPECIFIC GRAVITY SOLIDS)
PORE = WATER LOSS/((WATER LOSS + (DRY WGT/SOLIDS S.G.))
DRYDEN = DRY WEIGHT/((WATER LOSS + (DRY WGT/SOLIDS S.G.))
BLKDEN = WET WEIGHT/((WATER LOSS + (DRY WGT/SOLIDS S.G.))

FILE NAME.. coreaug.24
DATE....... 02-28-1986

TABLE BIO

Knight & Piesold Ltd
KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE 1
MOISTURE & DENSITY CALCULATED FROM CORE SAMPLES

site A cores

assumed solids specific gravity = 2.64 gm/cc

SAMPLE	TARE	TOTWET	TOTDRY	WET	DRY	WATER	CALCVOL	SOLID	WATER	M/C	PORE	DRYDEN	BLKDEN
#	(gm)	(gm)	(gm)	(gm)	(gm)	(gm)	(cc)	(%)	(%)	(%)	(m3/m3)	(t/m3)	(t/m3)
1-1 top	20.0	502.7	279.2	482.7	259.2	223.5	321.7	53.7	46.3	86.2	0.695	0.806	1.501
1-2	20.0	684.7	242.1	664.7	222.1	442.6	526.7	33.4	66.6	199.3	0.840	0.422	1.262
1-3	20.0	740.3	263.2	720.3	243.2	477.1	569.2	33.8	66.2	196.2	0.838	0.427	1.265
AVERAGE.......				1867.7	724.5	1143.2	1417.6	38.8	61.2	157.8	0.806	0.511	1.317
1-1 top	20.0	502.7	279.2	482.7	259.2	223.5	321.7	53.7	46.3	86.2	0.695	0.806	1.501
1-2	20.0	684.7	238.7	664.7	218.7	446.0	528.8	32.9	67.1	203.9	0.843	0.414	1.257
1-3	20.0	740.3	257.0	720.3	237.0	483.3	573.1	32.9	67.1	203.9	0.843	0.414	1.257
AVERAGE.......				1867.7	715.0	1152.7	1423.6	38.3	61.7	161.2	0.810	0.502	1.312
2-5 top	14.7	226.5	108.8	211.8	94.1	117.7	153.3	44.4	55.6	125.1	0.768	0.614	1.381
2-4	20.0	215.7	95.7	195.7	75.7	120.0	148.7	38.7	61.3	158.6	0.807	0.509	1.316
2-3	20.0	241.5	136.0	221.5	116.0	105.5	149.5	52.4	47.6	91.0	0.706	0.776	1.482
2-2	20.0	205.4	128.8	185.4	108.8	76.6	117.9	58.7	41.3	70.4	0.650	0.924	1.574
2-1	9.0	258.0	197.3	249.0	188.3	60.7	132.1	75.6	24.4	32.3	0.460	1.426	1.886
AVERAGE.......				1063.4	582.8	480.6	701.3	54.8	45.2	82.5	0.685	0.831	1.516
2-5 top	14.7	226.5	102.6	211.8	87.9	123.9	157.2	41.5	58.5	141.0	0.788	0.559	1.347
2-4	20.0	215.7	91.1	195.7	71.1	124.6	151.5	36.3	63.7	175.2	0.822	0.469	1.291
2-3	20.0	241.5	132.6	221.5	112.6	108.9	151.6	50.8	49.2	96.7	0.719	0.743	1.462
2-2	20.0	205.4	124.7	185.4	104.7	80.7	120.4	56.5	43.5	77.1	0.670	0.870	1.540
2-1	9.0	258.0	196.6	249.0	187.6	61.4	132.5	75.3	24.7	32.7	0.464	1.416	1.880
AVERAGE.......				1063.4	563.9	499.5	713.1	53.0	47.0	88.6	0.700	0.791	1.491
3-4	14.7	259.0	111.5	244.3	96.8	147.5	184.2	39.6	60.4	152.5	0.801	0.525	1.326
3-3	14.7	219.5	112.0	204.8	97.3	107.5	144.4	47.5	52.5	110.5	0.745	0.674	1.419
3-2	14.7	219.8	137.5	205.1	122.8	82.3	128.8	59.9	40.1	67.0	0.639	0.954	1.593
3-1	14.7	215.1	109.1	200.4	94.4	106.0	141.8	47.1	52.9	112.4	0.748	0.666	1.413
AVERAGE.......				854.6	411.2	443.4	599.1	48.1	51.9	107.8	0.740	0.686	1.426
3-4 top	14.7	259.0	104.0	244.3	89.3	155.0	188.8	36.6	63.4	173.6	0.821	0.473	1.294
3-3	14.7	219.5	107.7	204.8	93.0	111.8	147.0	45.4	54.6	120.2	0.760	0.633	1.393
3-2	14.7	219.8	134.2	205.1	119.5	85.6	130.9	58.3	41.7	71.6	0.654	0.913	1.567
3-1	14.7	215.1	103.5	200.4	88.8	111.6	145.2	44.3	55.7	125.7	0.768	0.611	1.380
AVERAGE.......				854.6	390.6	464.0	612.0	45.7	54.3	118.8	0.758	0.638	1.397

NOTES......

ALL CALCULATIONS ASSUME THAT SAMPLES ARE COMPLETELY SATURATED
CALCVOL = WATER VOL + (DRY WGT SOLIDS/SPECIFIC GRAVITY SOLIDS)
PORE = WATER LOSS/((WATER LOSS + (DRY WGT/SOLIDS S.G.))
DRYDEN = DRY WEIGHT/((WATER LOSS + (DRY WGT/SOLIDS S.G.))

TABLE B.11

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

SUMMARY OF RADON EXHALATION DATA COLLECTED

Date	Site	Time Interval (minutes)	Radon Conc. (pCi/L)	
			Unit 5	Unit 16
31/05/85	A	0-30	370	345
		30-59	1364	1582
		59-89	2655	2686
		89-119	4134	4380
		119-164	5780	6236
		164-292	9036	9849
31/05/85	TR	0-29	4522	4658
		29-59	3019	3233
		59-89	1722	1785
		89-184	611	590
		184-214	170	148
		214-243	153	87
		243-273	106	75
2/06/85	6BAR	0-29	598	663
		29-58	1946	1904
		58-119	3631	3887
		119-145	5124	5108
		145-174	5645	6325
		174-203	6396	6866
2/06/85	4BAR	0-132	7044	7508
		132-250	4943	5379
		250-342	3135	3440
11/07/85	A	0-14	210	217
		14-80	697	768
		80-130	1450	1587
		130-158	2207	2125
		158-179	2310	2682
		179-306	4150	4378
12/07/85	L2	0-18	441	428
		18-36	1168	1224
		36-52	1756	1749
		52-66	1997	2138
		66-80	2177	2149

Date	Site	Time Interval (minutes)	Radon Conc. Unit 5	(pCi/L) Unit 16
		80-18	2246	2218
		118-165	1941	2114
		165-193	1939	2069
		193-215	2189	2115
		215-296	2660	2743
13/07/85	BNCH	0-30	83	119
		30-53	526	268
		53-90	26	33
		90-129	43	31
		129-165	35	36
		165-194	60	52
		194-240	35	34
		240-316	35	52
		316-370	37	30
23/08/85	A	0-22	572	595
		22-41	1427	1603
		41-64	2192	2228
		64-86	2780	3046
		86-110	3207	3392
		110-134	3703	4016
		134-164	-	-
		164-183	3933	4247
		183-206	4018	4024
		206-251	4272	4480
24/08/85	MH	0-32	29	27
		32-48	33	49
		48-62	50	68
		62-99	42	19
		99-180	24	29
		180-296	34	28
		296-401	36	25
29/09/85	A	0-18	3128	894
		18-41	2435	925
		41-62	2266	1135
		62-81	1799	1358
		81-106	1931	1524
		106-123	2012	1808
		123-140	2096	1925
		140-190	2401	2285
26/10/85	A	0-23	554	702
		23-37	-	-
		37-47	5744	6030
		47-69	10120	11048

Date	Site	Time Interval (minutes)	Radon Conc. Unit 5	(pCi/L) Unit 16
		69-81	15835	18009
		81-100	20539	23864
		100-118	24620	29164
		118-125	28711	34141

APPENDIX C

CHEMICAL ANALYSES AND REPORT
BY CHEMEX LABORATORIES

REPORT FOR KNIGHT & PIESOLD

Project: Monitoring of Layered Uranium
Tailings - Phase II

November 8, 1985

REPORT FOR KNIGHT & PIESOLD

MONITORIING OF LAYERED URANIUM TAILINGS - PHASE II.

Two separate investigations concerning uranium tailings were carried out as instructed by Knight and Piesold Ltd.

The first investigation involved measuring the depletion of cations in tailings seepage water when subjected to a 10% suspension of various scavenging substrates over prolonged periods of time.

The second study involved the analysis of tailings solids and associated porewater for elemental and radioisotopic content.

Reference can be made to KPL letters dated April 15/85 (5/0317), June 12/85 (5/0471), Aug. 22/85 (5/0646), Sep. 3/85 (5/0684) and Oct. 23/85 (5/0791) with reference numbers in brackets and to Chemex Proposal dated May /85 for background terms of reference and scope of work.

I. SCAVENGING STUDY

1.1 Materials and Preparation

Forty litres of seepage water from an existing tailings facility were provided together with representative samples of sand, till, till/bentonite (1:0.03) and sandstone. The seepage water containers were observed to have residual material on the bottom characteristic of iron floc. Prior to using the seepage water it was filtered through a 0.45 u filter to remove any residual floc in suspension.

Substrate samples were prepared by drying the sand, till and sandstone. The sand and till samples were passed through an 18 mesh (1 mm) sieve. The -1 mm fractions were used in the scavenging studies without further preparation. The sandstone was agitated in a puck and ring pulverizer for 5 seconds. This length of time was judged to be satisfactory to desegregate the sandstone without appreciably pulverizing it. The -1 mm fraction of this desegregated material was used. A 3% by weight mixture of bentonite in till was prepared as the fourth substrate.

The seepage water and substrate samples were analysed separately as described in the following sections. The results are reported on Chemex cerificates A8516416 and A8516412 respectively.

1.2 Shaker Tests

Two hundred grams of substrate was added to 1.8 L of seepage water in heavy walled, acid rinsed and distilled water washed Nalgene bottles according to the "Test Schedule and Program" found in KPL letter Apr. 15/85 and reproduced below. Where an initial seepage water of pH 5 was required, the seepage water was adjusted with sulphuric acid and monitored by a pH meter before the substrate was added. Conductivity and pH were measured on each sample prior to shaking the samples. Nitrogen from a liquid nitrogen source was flushed into the head space of each sample container before it was sealed. The samples were shaken on a mechanical shaker for the prescribed times listed below.

At the end of the shaking period the samples were allowed to settle for several hours; pH and conductivity were again measured. The sample was then filtered through a 3 micron filter and an aliquot was retained for radium-226 analysis. The remainder of the sample was filtered through a 0.45 micron filter and analysed for all of the parameters listed on Chemex certificate A8516416.

TEST SCHEDULE AND PROGRAM

No.	Soil Type	pH	Time (hr)	pH	Cond.	Ra-226	Th Isotopes	U	As	Plasma Scan
1	sand	A.R.	24	X	X	X	X	X	X	X
2	sand	A.R.	72	X	X	X	-	X	X	X
3	sand	5.0	24	X	X	X	X	X	X	X
4	t/b	A.R.	24	X	X	X	X	X	X	X
5	t/b	A.R.	72	X	X	X	-	X	X	X
6	t/b	5.0	24	X	X	X	-	X	X	X
7	till	A.R.	24	X	X	X	X	X	X	X
8	till	A.R.	72	X	X	X	-	X	X	X
9	till	5.0	24	X	X	X	-	X	X	X
10	sandstone	A.R.	24	X	X	X	X	X	X	X
11	sandstone	A.R.	72	X	X	X	X	X	X	X
12	sandstone	5.0	24	X	X	X	X	X	X	X
13	sandstone	5.0	72	X	X	X	-	X	X	X
14	control	A.R.	24	X	X	X	X	X	X	X

t/b - till bentonite
A.R. - as received
Cond. - conductivity

1.3 Analytical Methods

1.3.1 Radium 226 :

A subsample of the filtrate is spiked with a barium radiotracer (Ba-133). Ra-226 and Ba-133 are co-precipitated from solution by barium sulphate. The barium tracer in the precipitate is gamma counted to determine the yield (90-100%). The samples are then alpha counted and the results compared to known radium 226 standards carried through the same procedure.

Absolute detection limit: 0.01 Bq.

1.3.2 Thorium Isotopes (Th-228, 230, 232) :

A subsample of the filtrate is spiked with the beta emitting radiotracer Th-234, lanthanum chloride as a carrier and barium nitrate as a holdback carrier for radium. Thorium isotopes are then co-precipitated with lanthanum fluoride. The isotopes are collected on a 0.45 micron filter and alpha counted using an Ortec Model 496 alpha spectrometer. The samples are also beta counted for Th-234 to determine the overall yield of the separation. The activity of samples is compared to those of known thorium standards carried through the same procedure.

Absolute detection limit for each of the three isotopes: 0.05 Bq.

1.3.3 Thorium-232 : (Alternate procedure for low levels)

Thorium-232 is determined colorimetrically as its arsenazo III complex. Thorium is separated initially by coprecipitation with lead sulfate, dissolved in a diethylenetriamine pentaacetate solution and extracted into bis(2-ethylhexyl)phosphoric acid. Finally thorium is back extracted into an aqueous solution of oxalic acid for spectrophotometric determination of Th 232 with arsenazo III. Color development is carried out in 3M HCl and the wavelength used to measure the thorium complex is 665 nm.

Thorium 232 is reported in activity units rather than concentration. Thorium 228 is assumed to have the same activity.

1.3.4 Uranium :

Natural uranium is determined fluorimetrically as its fluoride complex following extraction into methyl isobutyl ketone from an acid-deficient aluminum nitrate solution.

Detection limit: 0.05 ug/L

1.3.5 Arsenic :

Dissolved arsenic is reduced to As(III) with KI. The arsenic is then converted to arsine (arsenic trihydride) in a closed cell. The hydride is flushed into a heated tube in the optical path of an atomic absorption spectrometer where it is decomposed to elemental As which is then quantified by AAS.

1.3.6 ICP Multielement Analysis :

An aliquot of sample is preconcentrated by evaporation. The resulting sample solution is quantified by ICP to the following detection limits:

Be, Cd	0.5 - 2	ug/L
Ag, Co, Cr, Cu, Mn, Mo, Ni, Pb, Zn	5 - 10	ug/L
P, W	20 - 50	ug/L
Al, Ca, Fe, Mg, Na, Ti	500	ug/L

1.4 Comments

1) Arsenic values on the seepage water were originally determined as 200 ppb by ICP analysis. This value was considered to be approximate due to the method and nature of analysis. The initial arsenic values were determined 14 days later at the beginning of the shaker study to be 60 ppb. These values were determined by the hydride method and are considered more accurate.

   The large deviation of the two results is more than would be expected from the analytical procedures, however. It is possible that arsenic coprecipitated with the observed iron floc or that arsenate anions complexed with co- precipitating cations.

2) It was not possible to preconcentrate the seepage water samples to the degree that we had hoped. Attempts to preconcentrate the solution by evaporation led to the precipitation of calcium sulphate. Thus the detection limits reported for elements analysed by ICP are higher than intended.

3) Analytical precision was determined from duplicate analyses and was measured to be within +/- 10% for results that were at least an order or magnitude greater than the detection limit for that parameter. As the results approach the detection limit the precision becomes progressively poorer (ie +/- 100% at the detection limit).

4) The standard solution which was originally reported as 12.6 Bq/L for Ra 226 was reanalysed in quadruplicate to yield a mean value of 9.9 +/- 0.7 Bq/L. The higher value initially reported was calculated from a poorly resolved spectrum which should not have been used. As a result a number of degraded alpha particles from Rn 222 decay was erroneously counted as Ra 226.

II. Analysis of Tailings Solids and Pore Water

2.1 Materials and Preparation

Eight samples of saturated tailings were provided individually in plastic pails. They were sufficiently radioactive that they required a Level II Radioactivity Hazard Label and were thus treated with due caution.

Porewater samples from B1, B2, B3, B4 and A1 were obtained by simply decanting off the water that had separated from the solids during storage. Samples A2, A3 and A4 were much less saturated with water and appeared to contain a high level of plastic clay. A small amount of pore water was extracted from these samples using a cellulose filter on a porous plug and a 30 tonne hydraulic press. Approximately 50 ml of porewater was obtained from each of the three samples in this manner. This volume was sufficient to analyse all parameters requested except sulphate, alkalinity, and ammonia.

The eight tailings solids samples were spread out in individual aluminum trays. Two subsamples were taken from each quadrant of a tray to form a composite analytical sample. The eight solid samples for analysis were then dried and pulverized in a puck and ring pulverizer. Separate subsamples of A1 and A4 were retained for specific gravity determination. The prepared tailings solids were analysed as described below. The results are reported on Chemex certificate A8516412.

The porewater samples were analysed for Eh, pH and conductivity. They were then filtered through a 3 micron filter, a subsample was retained for Ra 226 analysis and the remainder of the sample was further filtered through a 0.45 micron filter. The samples were analysed as described below. The results are reported on Chemex certificate A8516414.

The remaining sample material is in storage for removal to a radioactive waste disposal area.

2.2 Analytical Methods :

Solid samples for each of the methods listed in Sec 1.3 were first digested in a mixture of hot nitric, perchloric and hydrofluoric acids. An aliquot of the digest solution was then analysed as described in the previous section.

In addition to the parameters described in Sec. 1.3 additional parameters were determined as follows:

2.2.1 Pb-210:

A tracer solution of stable lead and bismuth is added prior to digestion. Bismuth is then solvent-extracted and its recovery determined by atomic absorption spectrophotometry. Bismuth is then precipitated as bismuth oxychloride and beta-counted to measure Bi-210, the first daughter of Pb-210 and assumed to be in equilibrium with Pb-210 by virtue of its short half life. The absolute detection limit for Pb-210 is 0.05 Bq.

2.2.2 Po-210:

The sample digest solution is reduced with ascorbic acid, heated to 90 Deg. C and polonium-210 is allowed to spontaneously deposit onto a silver disc. The disc is then alpha counted to determine Po-210 activity. The absolute detection limit for Po-210 is 0.01 Bq.

2.2.3 Silica:

Silica is determined on the solid samples by fusing a 0.2 gm sample with a peroxide flux, dissolving the resulting silica salts in acetic acid and quantifying silica in solution by atomic absorption spectroscopy.

2.2.4. Sulphate:

Sulphate is determined in water samples by adding an excess of barium ions to the solution and quantifying the resulting barium sulphate precipitate either turbidimetrically for low concentrations or in this case gravimetrically for high concentrations of the sulphate ion.

Sulphate in solids is determined by leaching a known weight of solids in hot distilled water. The leach solution is then analysed as above.

2.2.5 CO2:

Carbon dioxide is determined by adding dilute hydrochloric acid to a known weight of sample in a closed vessel. The CO2 gas evolved is dried and then measured in a gas buret. The result is reported as the weight percent of calcium carbonate necessary to produce the amount of carbon dioxide measured.

2.2.6 Alkalinity:

Alkalinity is determined by potentiometric titration with sulphuric acid which has been standardized with sodium carbonate. The sample (if pH>8.3) is first titrated to a pH 8.3, which corresponds to the equivalence point for the conversion of carbonate to bicarbonate ion (phenolphthalein alkalinity). The titration is continued to a pH of 4.5 which corresponds approximately to the equivalence point for the conversion of bicarbonate to carbonic acid. The entire titre indicates total alkalinity as mg/L calcium carbonate.

2.2.7 Ammonia:

Ammonia is distilled from a water sample buffered at pH 7.4 and is collected in a boric acid solution. The ammonia in the distillate is then determined colorimetrically at 425 nm using Nessler's reagent.

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CERTIFICATE OF ANALYSIS

TO : KNIGHT AND PEISOLD LTD.
CONSULTING ENGINEERS
1350 - 409 GRANVILLE ST.
VANCOUVER, B.C.
V6C 1T2

CERT. # :A8516416
INVOICE # :
DATE : 31-OCT-85
P.O. # : NONE

Sample description	PH	Cond	As ppb	U ppb	Ni ppb	Mo ppb	Zn ppb	P ppb
SAND								
72 hr	3.9	2230	10	80	310	40	200	60
24 hr	4.7	2200	4.4	29	230	175	165	55
24 hr (PH 5)	4.3	2200	3.3	60	300	145	150	<50
Initial	6.3	2100	60	37	250	670	150	<50
SANDSTONE								
72 hr	6.5	2150	6.2	3	120	290	<5	60
72 hr (PH 5)	6.3	2140	6.3	6	220	115	5	<50
24 hr	5.5	2200	4	9	280	85	95	<50
24 hr (PH 5)	2.8	2900	17	34	300	205	170	80
Initial	6.3	2100	60	37	250	670	150	<50
TILL								
72 hr	5.0	2150	10	11	380	40	110	60
24 hr	5.9	2200	6.3	6	260	630	<5	80
24 hr (PH 5)	6.4	2200	5.8	9	320	480	55	75
Initial	6.3	2100	60	37	250	670	150	<50
TILL/BENTONITE								
72 hr	6.3	2250	1.6	3	290	480	5	80
24 hr	6.9	2300	28	11	160	610	<5	275
24 hr (PH 5)	6.6	2300	22	4	220	560	<5	240
Initial	6.3	2100	60	37	240	670	150	<50
CONTROL								
24 hr	4.4	2200	68	30	230	645	150	<50
STD	--	--	2050	1.0	930	--	--	--

Sulphate ion concentration of the seepage water - 1350 ppm. Other elements quantified by ICP analysis were less than the detection limit and showed no variation. These elements and their detection limits in brackets are as follows :
W(50), Pb (5), Bi(10, Cd(2), Ba(50), Fe(0.5), Cn(50), Mg(0.5), V(5), Al(0.5), Be(2), Cu(5), Ti(0.05)

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CERT. # : A8516416
INVOICE # :
DATE : 31-OCT-85
P.O. # : NONE

'SCAVANGING STUDY'

Sample description	Mn ppb	Sr ppb	Co ppb	Ca ppm	Na ppm	K ppm	Th230 Bq/L	Th232,228 Bq/L	Ra226 Bq/L
SAND									
72 hr	950	1030	15	525	35	11	-	-	9.9
24 hr	910	940	15	560	36	10	0.26	0.13	10.5
24 hr (PH 5)	950	855	10	530	33	9	0.56	0.11	9.6
Initial	805	880	10	550	35	9	0.66	0.26	16.5
SANDSTONE									
72 hr	1450	1600	5	530	35	11	-	-	5.8
72 hr (PH 5)	1450	1370	10	520	32	10	0.30	0.26	6.1
24 hr	1250	870	10	490	30	9	0.36	0.20	8.4
24 hr (PH 5)	1800	960	15	565	35	11	0.66	0.26	9.6
Initial	805	880	10	550	35	9	0.66	0.26	16.5
TILL									
72 hr	980	970	15	535	36	12	-	-	5.7
24 hr	910	855	15	605	36	11	0.59	0.19	4.1
24 hr (PH 5)	880	855	15	525	33	10	-	-	1.9
Initial	805	880	10	550	35	9	0.66	0.26	16.5
TILL/BENTONITE									
72 hr	1280	1050	10	485	78	12	-	-	0.45
24 hr	730	955	<5	490	76	11	0.33	0.15	1.8
24 hr (PH 5)	865	880	5	465	71	10	-	-	1.5
Initial	805	880	10	550	35	9	0.66	0.26	16.5
CONTROL									
24 hr	765	805	10	510	35	9	0.69	0.26	17.1
STD								-	12.6

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CERTIF. # : A8516412
INVOICE # :
DATE : 31-OCT-85
P.O. # : NONE

'SUBSTRATE'

Sample description	SAND	SAND-STONE	TILL	TILL/BENTONITE
Mo ppm	<1	<1	<1	<1
W ppm	<10	<10	<10	<10
Zn ppm	3	<1	3	6
P ppm	60	70	75	80
Pb ppm	7	3	7	11
Bi ppm	<2	<2	<2	<2
Cd ppm	0.5	0.5	0.5	0.5
Co ppm	<1	<1	<1	<1
Ni ppm	7	7	9	6
Ba ppm	40	30	220	15
Fe %	0.29	0.30	0.38	0.25
Mn ppm	9	9	19	8
[illegible]r ppm	155	145	145	130
Mg %	0.02	0.01	0.06	0.03
V ppm	6	6	8	9
Al %	0.47	0.39	0.62	1.19
Be ppm	<0.5	<0.5	<0.5	<0.5
Ca %	0.04	0.02	0.05	<0.01
Cu ppm	<1	<1	<1	<1
Ti %	0.018	0.031	0.032	0.020
Sr ppm	56	35	39	73
Na %	0.14	0.09	0.15	0.01
K %	0.09	0.06	0.07	0.12
As ppm	<2	<2	<2	<2
U ppm	0.6	0.2	0.3	0.5

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CERTIF. # : A8516412
INVOICE # :
DATE : 31-OCT-85
P.O. # : NONE

'TAILING SOLIDS'

Sample description	A1	A2	A3	A4	B1	B2	B3	B4
Mo ppm	2	<1	<1	<1	<1	3	1	<1
W ppm	45	45	35	35	50	25	30	10
Zn ppm	1030	1220	1290	1380	995	965	815	635
P ppm	675	500	445	425	480	380	380	345
Pb ppm	1700	1290	1130	1290	1740	1460	1430	1020
Bi ppm	185	185	165	180	180	175	180	135
Cd ppm	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Co ppm	560	435	420	455	510	480	480	350
Ni %	1.90	1.85	1.69	1.77	1.65	1.20	1.43	1.09
Ba ppm	380	365	210	290	485	490	240	140
Fe %	2.66	2.43	2.35	2.31	2.29	1.77	1.94	1.47
Mn ppm	230	205	215	195	170	128	133	92
[illegible]r ppm	115	100	100	100	115	110	145	90
Mg %	1.09	1.04	1.24	1.10	1.14	0.74	0.92	0.66
V ppm	505	400	360	345	420	340	355	265
Al %	4.00	3.96	3.78	3.51	4.47	3.36	3.79	2.51
Si %	40.1	33.9	38.4	42.8	42.0	60.1	57.7	69.8
Be ppm	8.0	7.0	7.0	6.5	7.5	6.0	6.0	3.5
Ca %	7.60	10.20	11.80	10.20	9.84	5.33	5.63	4.02
Cu ppm	485	445	410	375	430	395	480	300
Ti %	0.231	0.164	0.154	0.163	0.221	0.180	0.219	0.161
Sr ppm	149	137	131	123	161	132	122	96
Na %	0.09	0.29	0.12	0.11	0.15	0.20	0.11	0.07
K %	0.30	0.37	0.32	0.32	0.42	0.24	0.29	0.20
As %	1.2	1.1	1.1	1.1	1.0	0.81	1.0	0.77
U ppm	790	580	465	530	490	550	840	1430
SO4 %	15	16	16	14	12	11	9.9	6.3
CO2 % (CaCO3)	0.82	2.4	2.3	2.9	3.3	0.71	0.94	0.97
Ra 226 Bq/gm	315	312	224	228	275	246	215	150
Th 230 Bq/gm	237	262	214	245	264	161	169	118
Pb 210 Bq/gm	315	329	214	258	311	274	220	141
Po 210 Bq/gm	300	323	180	230	285	273	209	145

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V6C 1T2

CERT. # : A8516414
INVOICE # :
DATE : 09-OCT-85
P.O. # : NONE

"POREWATER SAMPLES"

Sample description	A1	A2	A3	A4	B1	B2	B3	B4
Mo ppb	1730	950	580	1010	910	1460	2300	3040
W ppb	1210	560	<250	280	175	1120	1110	590
Zn ppb	<5	<25	<25	<25	<5	<5	<5	50
P ppb	115	<250	<250	<250	55	155	60	145
Pb ppb	5	<25	<25	80	15	25	15	20
Bi ppb	<10	<50	<50	<50	<10	<10	<10	<10
Cd ppb	<2	<10	<10	<10	<2	<2	<2	<2
Co ppb	<5	<25	<25	<25	<5	<5	<5	<5
Ni ppb	170	355	265	560	85	285	230	355
Ba ppb	<50	<250	<250	<250	<50	<50	<50	<50
Fe ppm	<0.5	<2.5	<2.5	<2.5	<0.5	<0.5	<0.5	<0.5
Mn ppb	<5	<25	<25	<25	<5	<5	<5	<5
Cr ppb	<50	<250	<250	<250	55	<50	<50	<50
Mg ppm	<0.5	<2.5	<2.5	<2.5	<0.5	<0.5	<0.5	<0.5
V ppb	70	<25	95	60	120	65	75	75
Al ppm	<0.5	<2.5	<2.5	<2.5	<0.5	<0.5	<0.5	<0.5
Be ppb	<2	<10	<10	<10	<2	<2	<2	<2
Ca ppm	615	675	680	765	615	670	675	750
Cu ppb	35	125	135	100	80	45	55	75
Ti ppm	<0.05	<0.25	<0.25	<0.25	<0.05	<0.05	<0.05	<0.05
Sr ppb	845	1860	3180	2740	2120	1000	1690	2360
Na ppm	71.5	56.0	42.5	57.5	97.0	110	114	128
K ppm	11.5	19.0	20.5	18.0	21.5	18.5	19.0	29.5
As ppm	6.420	3.660	1.700	3.140	0.615	7.430	6.000	13.000
SO4 mg/L	1600	1700	1500	1800	1500	1700	1600	1600
pH	9.1	7.5	9.2	7.4	10.9	7.8	8.9	8.9
Cond.	2230	2860	2800	3000	2230	2480	2300	2400
Eh	290	--	--	--	230	320	290	280
U ppb	3.9	2.4	0.7	2.7	0.2	3.6	8.4	10.0
Alkal mg/L (CaCO3)	142	--	--	--	129	78	43	--
NH3 mg/L N	--	--	--	--	27	20	18	--
Ra 226 Bq/L	71.6	167.6	102.5	142.6	56.4	53.5	65.3	118.9
Th 230 Bq/L	0.66	0.62	0.62	0.49	1.09	0.89	0.33	0.53

VOI rev. 4/85

CERTIFIED BY:

KNIGHT AND PIESOLD LTD.

Attention: Mr. Harvey Dew

Specific Gravity results on samples A1 and A4 are as follows:

Sample	S.G. on sample Dried @ 45 Deg. C	S.G. on sample Dried @ 220 Deg. C
A1	2.39	2.67
A4	2.23	2.65

Subsamples of A1 and A4 were dried at 45 Deg. C and 220 Deg.C. The specific gravity was determined by picnometer using high purity methanol as the solvent rather than water.

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CERTIFICATE OF ANALYSIS

TO : KNIGHT & PIESOLD LTD.
CONSULTING ENGINEERINGS
1350 - 409 GRANVILLE ST.
NORTH VANCOUVER, B. C.
V6C 1T2

CERTIF. # : W 4243
INVOICE # :
DATE : 24-OCT-85
P.O. # : NONE

ATTN:

PARTICLE SIZING "MILL PROCESS SAMPLE"

Particle Size	Cummulative Wt %	Size Interval	Wt %
> 0 φ (1 mm)	1.7	> 0 φ	1.7
1 φ (0.5 mm)	7.5	1 φ - 0 φ	5.8
2 φ (0.25 mm)	67.0	2 φ - 1 φ	59.5
3 φ (0.125 mm)	71.5	3 φ - 2 φ	4.5
4 φ (63 µ)	73.4	4 φ - 3 φ	1.9
5 φ (32 µ)	78.7	5 φ - 4 φ	5.3
6 φ (16 µ)	83.4	6 φ - 5 φ	4.7
7 φ (8 µ)	87.8	7 φ - 6 φ	4.4
8 φ (4 µ)	91.9	8 φ - 7 φ	4.1
9 φ (2 µ)	94.6	9 φ - 3 φ	2.7
< 9 φ (2 µ)	100.2	< 9 φ	5.6

Certified by

Chemex Labs Ltd.

Analytical Chemists • Geochemists • Registered Assayers

212 Brooksbank Ave.
North Vancouver, B.C.
Canada V7J 2C1
Phone: (604) 984-0221
Telex: 043-52597

CERTIFICATE OF ANALYSIS

TO : KNIGHT AND PIESOLD
CONSULTING ENGINEERS
1350 - 409 GRANVILLE ST.
VANCOUVER, B.C.
V6C 1T2

CERT. # : W4299
INVOICE # : I8581389
DATE : 18-NOV-85
P.O. # : NONE
PARTICLE SPRING

ATTN:

Sample description	Moisture %	Clay fraction	44 µm	63 µm	125 µm	250 µm	500 µm	1.0 mm
A1	44.7	74.6	3.8	9.3	9.2	2.5	0.4	0.2
A2	57.1	61.8	3.3	7.3	10.4	8.0	3.7	5.5
A3	55.3	56.6	3.2	10.0	13.3	10.9	4.0	2.0
A4	53.8	43.7	3.1	6.2	17.5	19.8	6.3	3.4
B1	56.0	34.1	3.8	11.1	29.3	19.0	0.5	2.2
B2	46.0	84.2	4.0	6.0	3.8	1.2	0.4	0.4
B3	49.7	68.5	4.2	8.3	10.4	8.4	0.2	<0.1
B4	37.6	63.9	5.1	9.6	14.7	6.0	0.3	0.4

Please Note: Fractions 500µm + 1.00 mm appeared to be clay fractions that were too hardened to break during wet sieving.

VOI rev. 4/85

Certified by ....

Chemex Labs Ltd.

Analytical Chemists • Geochemists • Registered Assayers

212 Brooksbank Ave.
North Vancouver, B.C.
Canada V7J 2C1
Phone: (604) 984-0221
Telex: 043-52597

CERTIFICATE OF ANALYSIS

TO : KNIGHT AND PIESOLD LTD.
CONSULTING ENGINEERS
1350 - 409 GRANVILLE ST.
VANCOUVER, B.C.
V6C 1T2

** CERT. # : A8518633-001-A
INVOICE # : I8518633
DATE : 18-DEC-85
P.O. # : NONE
1603

ADDED PARAMETER

SAMPLES DATED OCT 26/85

Parameter Description	Sample # 1	Sample # 2	Sample # 3	Sample # 4	Sample # 5
Sample preparation code	221	221	221	221	221
pH	5.8	11.8	11.6	11.0	7.3
As ppb (dissolved)	--	140.0	750.0	490.0	--
Ni ppb (dissolved)	--	2	4	6	--
Ra-226 Bq/L dis	9.50	308.00	211.00	217.00	18.60
Sulphate/SO2/SO3 (mg/L)**	--	1390.00	1120.00	1190.00	--

Sample 1 - Seepage collected under Site A.
Sample 2 - Decant from fresh settled tailings.
Sample 3 - Decant from fresh tailings after freezing.
Sample 4 - Additional pore water from fresh tailings after initially settling decanting and freezing.
Sample 5 - Duplicate of Sample 1.

Sample description information	
Sample # 1	S 1
Sample # 2	S 2
Sample # 3	S 3
Sample # 4	S 4
Sample # 5	S 5

Preparation code description	
221	Water sample

VOI rev 4/8

Certified by ....

APPENDIX C

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE II

ANALYSIS OF STANDARDS

Standard	Known Concentration	Chemex Analysis	Repeat
Ni	1.00 mg/l	0.93 mg/l	
As	2.00 mg/l	2.05 mg/l	
Ra 226	9.2 Bq/l	12.6 Bq/l	9.9 Bq/l

APPENDIX D1

REPORT ON MINERALOGY OF KEY LAKE SAMPLES B1 AND B2 BY SASKATCHEWAN RESEARCH COUNCIL

MINERALOGY OF KEY LAKE TAILINGS SAMPLES B1 AND A3

by

R.G. Arnold

R-855-1-C-86 January, 1986

Introduction

The objective of the present project was to determine the mineralogy of Ni, As and Ra in Key Lake tailings. The work reported here is an extension of the mineralogical work reported previously to Knight and Piesold (Arnold, 1985)[1]

The previous work on Key Lake tailings samples showed that Ni occurs principally in the sulfides NiS (millerite), $(Ni,Fe)S_2$ (bravoite) and the arsenide (Ni,Fe)AsS (gersdorffite); whereas, arsenic occurs principally in gersdorffite. No information on the mode of occurrence of Ra was obtained from the previous study.

Sample Treatment

The majority of the work reported in the present study was undertaken on Key Lake tailings sample B1. Preliminary work was done on sample A3, but only the geochemical analysis for the heavy mineral fraction, obtained by superpanning, and a gypsum sample extracted by water leaching are reported here.

Sample B1, as received from the field, was divided into two portions. One portion was split into grain size fractions. The various plus 325 mesh (.042 mm) fractions were obtained by sieving; whereas, the minus 325 mesh fractions were obtained by standard sedimentation methods. The grain size intervals are listed in Table 1, and the grain size distributions are plotted in Fig. 1.

---

[1] Arnold, R.G. Mineralogy of Key Lake Tailings Samples A3 and A7. SRC Report R-860-1-C-85, February, 1985.

The second portion of sample B1 was subjected to a series of successive chemical leaching experiments in an attempt to extract the metals of interest and determine in what chemical form the metals occur in the sample. The leaches were performed successively on the sample in the following order: water, 14.8M NH_3, 8.75M NH_4Ac, 2.25N NaOH, 10N NaOH. The results of the leaching experiments are summarized in Table 2.

A small sample of white to yellow to brown pisoliths (pea-shaped grains) was concentrated for analysis by hand picking. The analysis of this sample is reported in Table 1.

Due to financial constraints, only 9 samples were analysed for Ra 226. The results are summarized in Tables 1 and 2. In addition, the total radioactivity (TR) of all samples (pisoliths excluded) was estimated and is expressed as the number of counts for 2 minutes per milligram of solid material (Tables 1 and 2). The total radioactivity values, although rather approximate, were used as a guide in selecting samples for Ra analysis. The total radioactivity values seem to be related to the Ra content of the samples in a general way, and serve the purpose of indicating if the Ra content is high, medium or low.

Geochemical Analyses

The various grain size fractions, gypsum, heavy minerals and a small sample of pisoliths were analysed for Ni and As and a suite of elements that were part of the standard ICP package of analysis. Selected results are summarized in Table 1.

The results in Table 1 show that the concentration of all metals listed generally increases with decreasing grain size, except for minor reversals in this trend. The Ni/As ratios for all grain sizes fractions range between 0.6 and 1.8 with a mean value of about 1.3. This suggests that the mineralogy of Ni and As, and the proportion of Ni and As bearing minerals is similar in the size fractions. The fluctuations in the ratio from one size fraction to another can readily be explained on the basis of small variations in the relative quantities of Ni and As bearing minerals from one size fraction to another.

Analysis of the gypsum sample obtained by evaporation of leach water (Table 1) shows that it is generally low in metals. The one exception is As which had a concentration of 0.11 %. The relatively high As content is probably not due to arsenide particulate impurities remaining from the concentration process, because Ni would then also be correspondingly high. This is shown by the low Ni/As ratio of 0.08 for the gypsum sample. If the As concentration was due to the presence of arsenide, the Ni/As ratio would be about 0.8. The relatively high As content in the gypsum sample suggests the presence of a water leachable

As compound. The possible compounds involved are discussed in the section on the leaching experiments.

The analysis of the heavy mineral fraction of sample A3 shows a very high concentration of Ni relative to As. The Ni/As ratio for the heavy mineral fraction is 11.8 compared to 0.6 - 1.8 for the various grain size fractions. This is probably due to a disproportionate concentration of Ni sulfides (probably millerite) in the sample relative to Ni arsenide, because the As concentration is not correspondingly high. This interpretation is supported by the high sulfur content of the heavy mineral fraction (20.9 wt.% S), as compared to 4.1 wt.% S for one of the grain size fractions (.063 to .043 mm fraction).

A few milligrams of pisoliths was analysed and was found to contain considerable Ni and As (Table 1). The ratio of Ni/As in pisoliths is 4.1 which is somewhat higher than for the various size fractions.

There is a considerable amount of cobalt in the heavy mineral fraction and in some of the grain size factions. Cobalt probably substitutes for nickel in the various Ni bearing minerals, and occurs in the sulfide linnaeite (Co_3S_4) as determined by the previous study. The Ni/Co ratio for the heavy mineral fraction is 24.3, and for the various size fractions it ranges between 15.8 and 32.3.

The Ra and total radioactivity data (Table 1), either show or suggest, that all grain size fractions contain measurable concentrations of Ra, and that the Ra has a tendency to increase with decreasing grain size. As the clay mineral content of the samples also increases with decreasing grain size, there may be an association between Ra and clay minerals. The occurrence of an intermediate concentration of Ra with the heavy mineral fraction is perhaps surprising as this sample consists primarily of sulfides and arsenides. The fact that Ra appears to occur in all mineral fractions, including the heavy minerals, suggests that Ra ions have the rather insidious ability to become adsorbed onto almost any mineral.

The gypsum sample (Table 1), concentrated by water leaching, contained no measurable radioactivity, suggesting that the compound containing Ra is not appreciably water soluble. This is confirmed by the lack of measurable radioactivity in gypsum from sample B1 (Table 2).

Electron Microprobe Analyses

Several polished sections were prepared from intermediate grain size fractions for electron microprobe studies. The known Ni and As bearing minerals were readily identified. Microprobe work showed that both Ni and As occur in pisoliths. Fig. 2 shows the relative metal concentrations on an arbitrary scale in the shell and interior of the pisoliths using energy dispersive spectrometry. Previous work had shown that the shells are quartz-rich and the interior consists primarily of gypsum. This was confirmed by the present microprobe work. The microprobe work shows that most of the Ni and As are concentrated in the shells. Based on the geochemical analysis of pisoliths (Table 1) and the microprobe results, it was estimated that the pisolith shells can contain up to 8% Ni and 2% As. The Ni and As minerals occurring in the shells is not known.

A series of mineral grains was discovered that contained variable concentrations of Fe, Ni, Si, Al with minor amounts of one or more of K, Ca, As and Mg. Based on net counts, the dominant elements in many of these grains are Si, Fe and Ni as shown in Fig. 3. It is possible that this material is a Ni-rich clay mineral.

X-ray Diffraction Work

X-ray diffraction charts were taken of each grain size fraction. They showed the presence of quartz and the expected clay minerals illite and trichlorite and very little else. Ni and As bearing minerals were below the limit of detectibility of the XRD method which is normally a few percent of the mineral.

One result obtained from the XRD charts was that the clay minerals in the grain size fractions produced poor diffraction peaks which is normally interpreted as reflecting poor crystallinity. For example, an XRD chart for clay minerals from unprocessed Key Lake ore samples (Fig. 4) shows strong, well formed diffraction peaks; whereas, a pattern for the minus 0.007 mm fraction from tailings (Fig. 5), shows low intensity and poorly formed peaks. Given similar smear-slide preparation, quantity of sample and machine settings, this suggests that the clay minerals in the tailings have undergone a structural deterioration in the milling process.

A suggestion was made that clay minerals might be destroyed in the mill treatment, and that new clay minerals might form in the tailings perhaps incorporating some Ni. Although, there is no direct evidence for this, clay minerals do form readily at earth surface conditions during weathering processes given adequate time and the appropriate physical and chemical environment.

The occurrence of amorphous material reported from the initial mineralogical work was not confirmed from the current work. It is suspected that the "amorphous hump" observed on several diffraction patterns may have been due to x-ray scatter by the glass smear-slides when the quantity of sample was relatively small.

Leaching Experiments

A portion of sample B1 was subjected to a series of successive leaches in the following order: H_2O, 14.8M NH_3, 8.75M NH_4Ac, 2.25N NaOH, 10N NaOH. The results in terms of percent metal extracted for As, Ni, Ba and Ra are summarized in Table 2.

The results provide clues as to the possible compounds containing these metals. Approximately 22.7% As was extracted by the water leach (pH of slurry was about 8) together with a large quantity of gypsum. This result confirms the presence of a water soluble As compound leached with gypsum as indicated in Table 1. It is possible that the water soluble As occurred as H_3AsO_4 (slightly soluble at a wide range of pH) or as $Ca(H_2AsO_4)_2$ (soluble at pH 4 to 7, and slightly soluble at higher values).

About 22% As was extracted by 2.25N NaOH and 13% As was extracted by 10N NaOH. Extraction by weak and strong alkali suggests that some As may be bound up in heavy metal arsenate, possibly a calcium arsenate because of the abundance of Ca in the tailings, such as: $CaHAsO_4$ or $3Ca_3(AsO_4)_2.Ca(OH)_2$ (soluble at pH 8 to 12). About 40% As remained in the final residue probably as gersdorffite.

Very little Ni was extracted by the water or NH_3 leach, indicating that little Ni occurred as water soluble $NiSO_4$, or as NH3 soluble metal salts of weak acids, such as $NiHAsO_4$ or $NiHPO_4$ (soluble at pH 5 to 10). About 5.2% Ni was extracted by the NH_4Ac leach, however, the compound of Ni that dissolved is not known. In any case, 93.6% Ni remained undissolved in the residue probably as sulfide and arsenide.

The results in Table 2 indicate that no measureable Ra was extracted by the water leach, a small quantity was extracted by the NH_3 leach, but that a significant quantity of Ra was extracted by the NH_4AC treatment. This Ra probably occurred as sulfate. It may be significant that 28% of the total Ba in the sample was extracted with Ra. This might suggest the presence of a radium-barium sulfate compound. The total radioactivity measurements suggest that a significant quantity of Ra remained in the residue together with 64% of the total Ba.

TABLE 1. Selected geochemical analyses of grain size fractions (B1), gypsum (A3), a heavy mineral concentrate (A3), and pisoliths (B1). B1 and A3 are sample numbers.

	Percent				PPM				Bq/g	
Grain Size(mm)	As	Ni/As	Ni	Pb	Mo	Ni/Co	Co	V	Ra	TR*
.425 to .180	0.62	0.7	0.44	0.04	5	20.4	216	110	60	48
.180 to .106	0.44	1.8	0.82	0.06	5	21.0	390	142	36	36
.106 to .075	0.64	1.6	1.03	0.08	6	16.9	611	165	85	23
.075 to .063	0.89	1.6	1.46	0.10	5	18.6	785	224	-	67
.063 to .043	1.15	1.6	1.88	0.13	9	16.7	1123	231	-	46
.043 to .0312	2.42	1.6	3.79	0.20	9	15.8	2400	337	-	51
.0312 to .0156	2.44	1.1	2.60	0.18	5	17.4	1493	399	200	79
.0156 to .007	5.85	0.6	3.24	0.26	6	24.9	1301	572	580	133
minus .007	2.80	1.1	3.05	0.28	4	32.3	943	599	570	204
Gypsum	0.114	0.09	0.01	0.01	43	-	1	34	-	0
Heavy Minerals	2.06	11.8	24.3	1.22	100	24.3	1%	638	170	44
Pisoliths	0.94	4.1	3.9	(Fe_2O_3 - 5.4%) (CaO - 23.9%)					-	-

* Total radioactivity: counts/2 minutes/mg

TABLE 2. As, Ni and Ra extracted from sample B1 by various leach reagents expressed as the % of total metal extracted.

Reagent	As %	Ni %	Ba %	Ra (Bq/g)	TR*
H_2O	22.7	.13	4	-	0
NH_3	.2	.15	-	-	3
NH_4Ac	1.3	5.2	28	1100	154
2.25N NaOH	22.3	.4	1	85	63
10N NaOH	13.1	.4	3	-	39
Residue	40.4	93.6	64	-	56
Totals	100	100	100		

* Total radioactivity: counts/2 minutes/mg

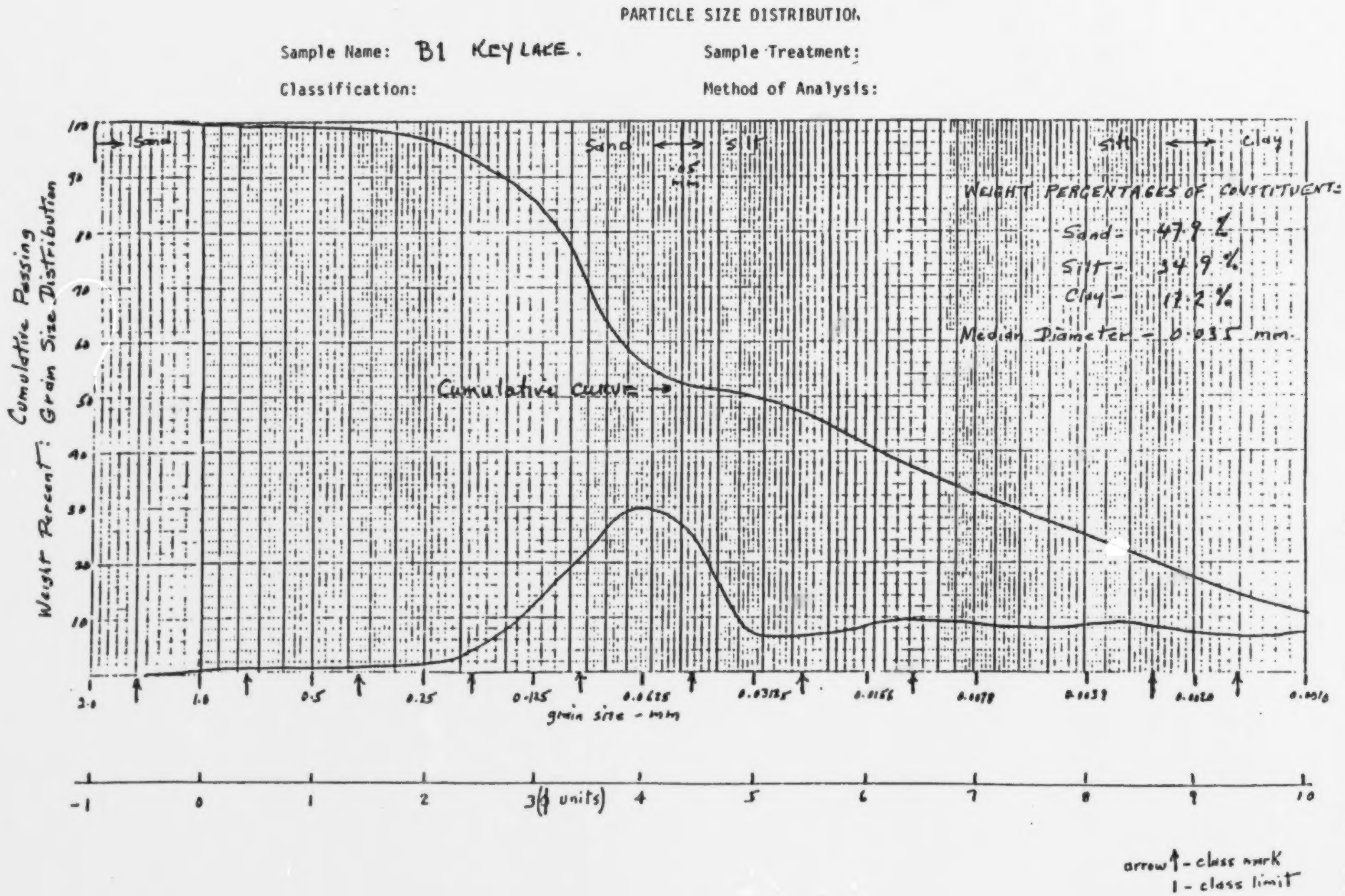


Fig. 1 Grain size distributions for Key Lake Tailings sample B1.

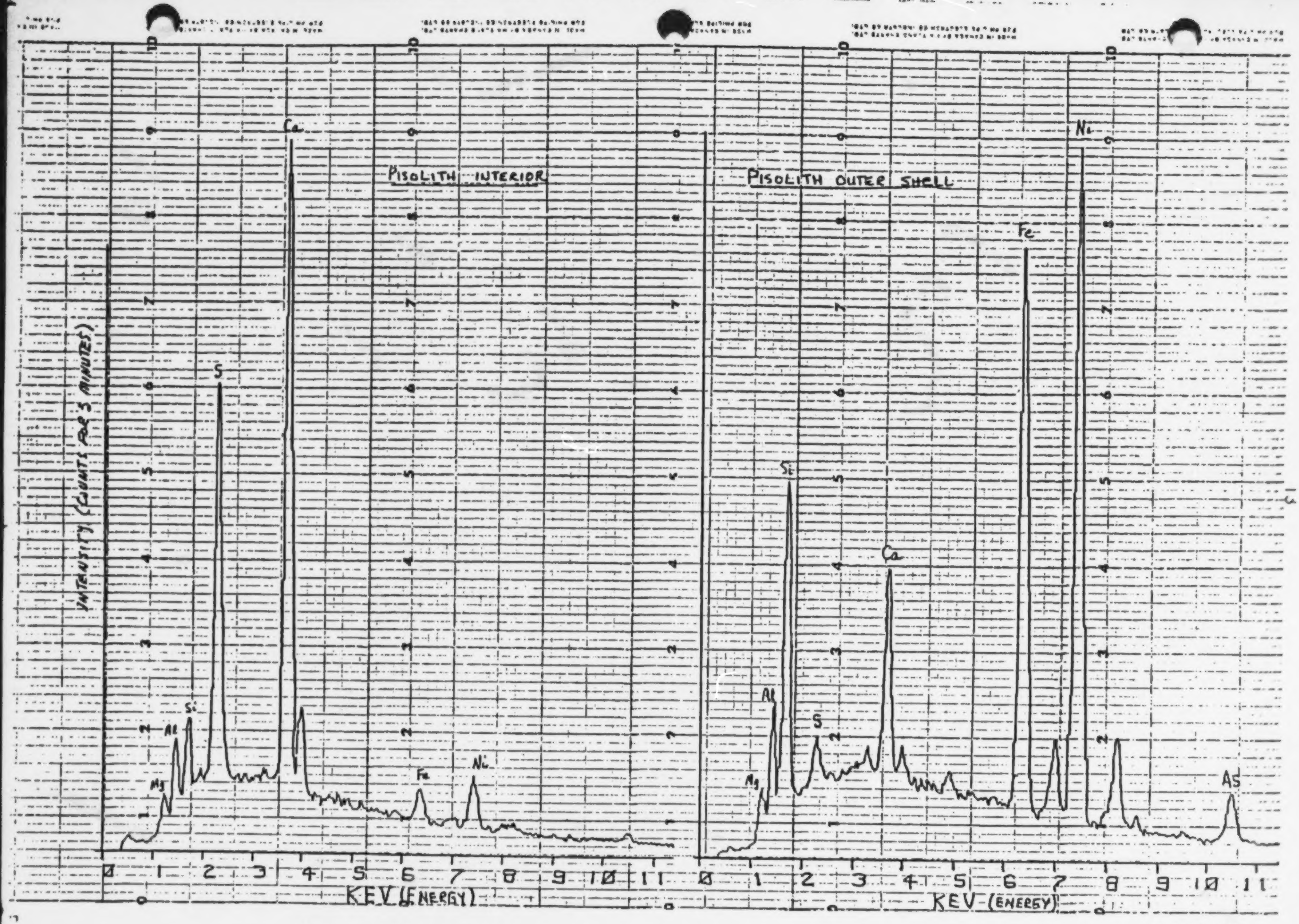


Fig. 2 Element distributions in a pisolth as determined by non-dispersive electron microprobe analysis.

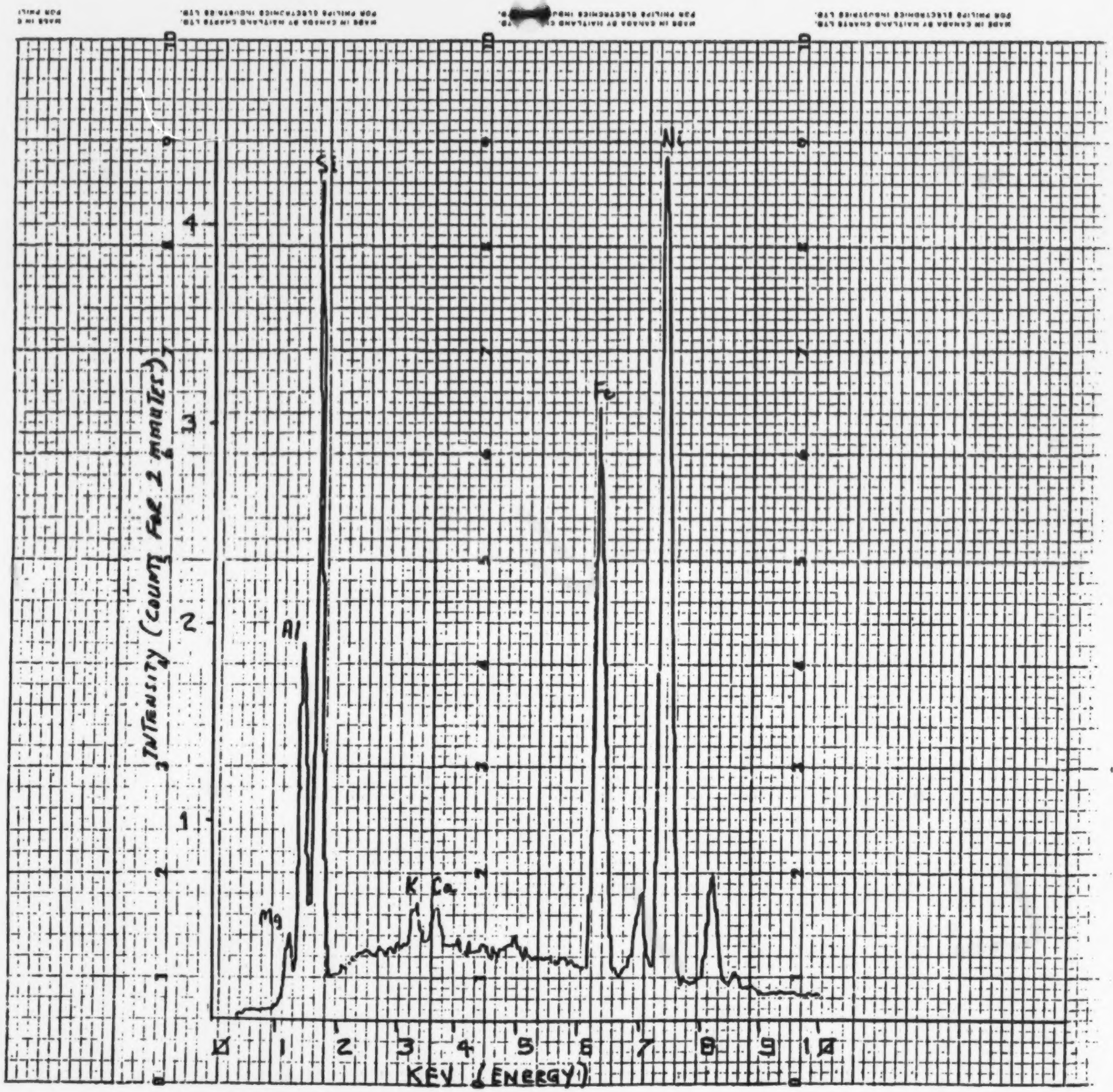


Fig. 3 Element content of a clay mineral (?) as determined by non-dispersive electron microprobe analysis.

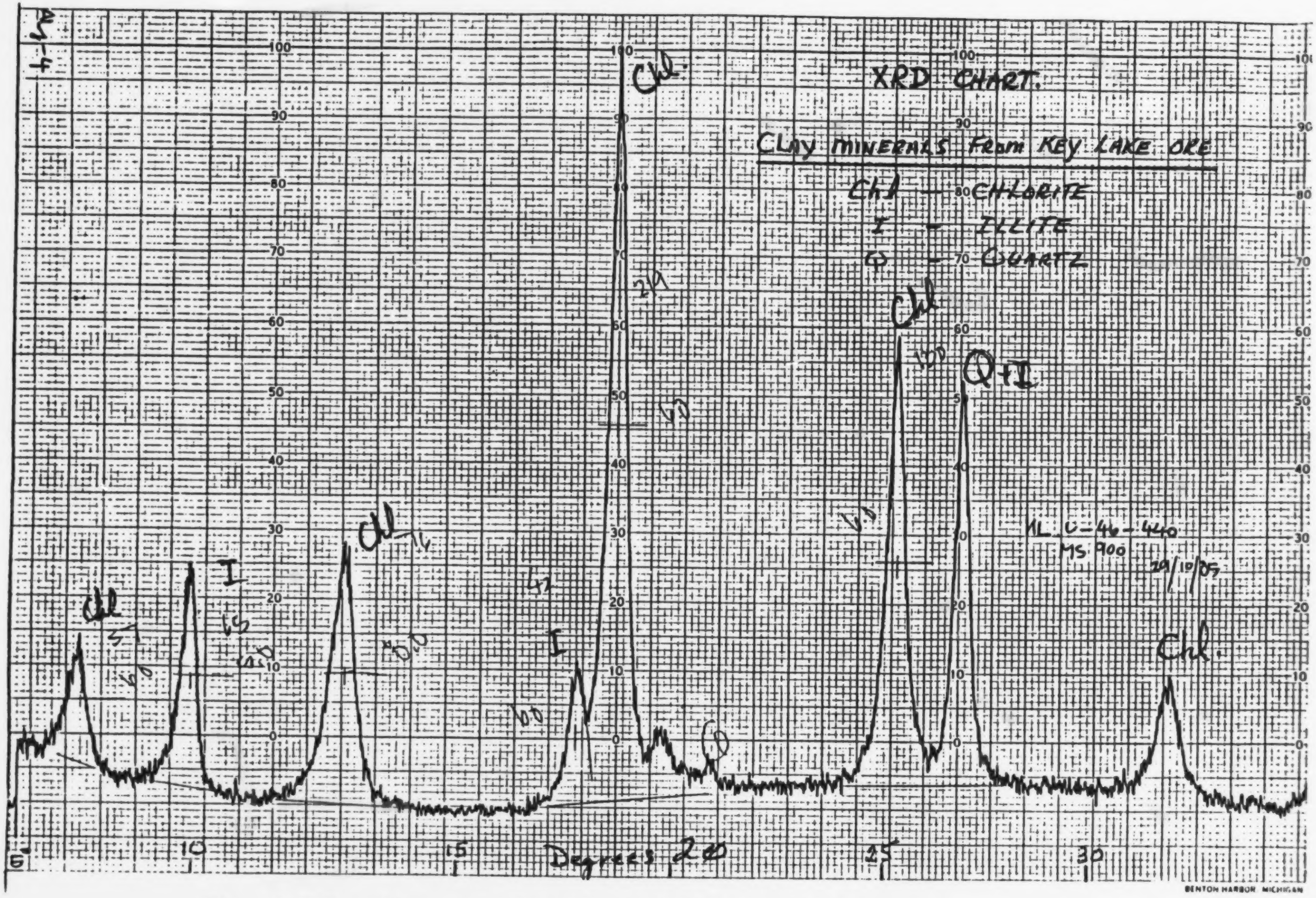


Fig. 4 XRD pattern of clay minerals in unprocessed ore.

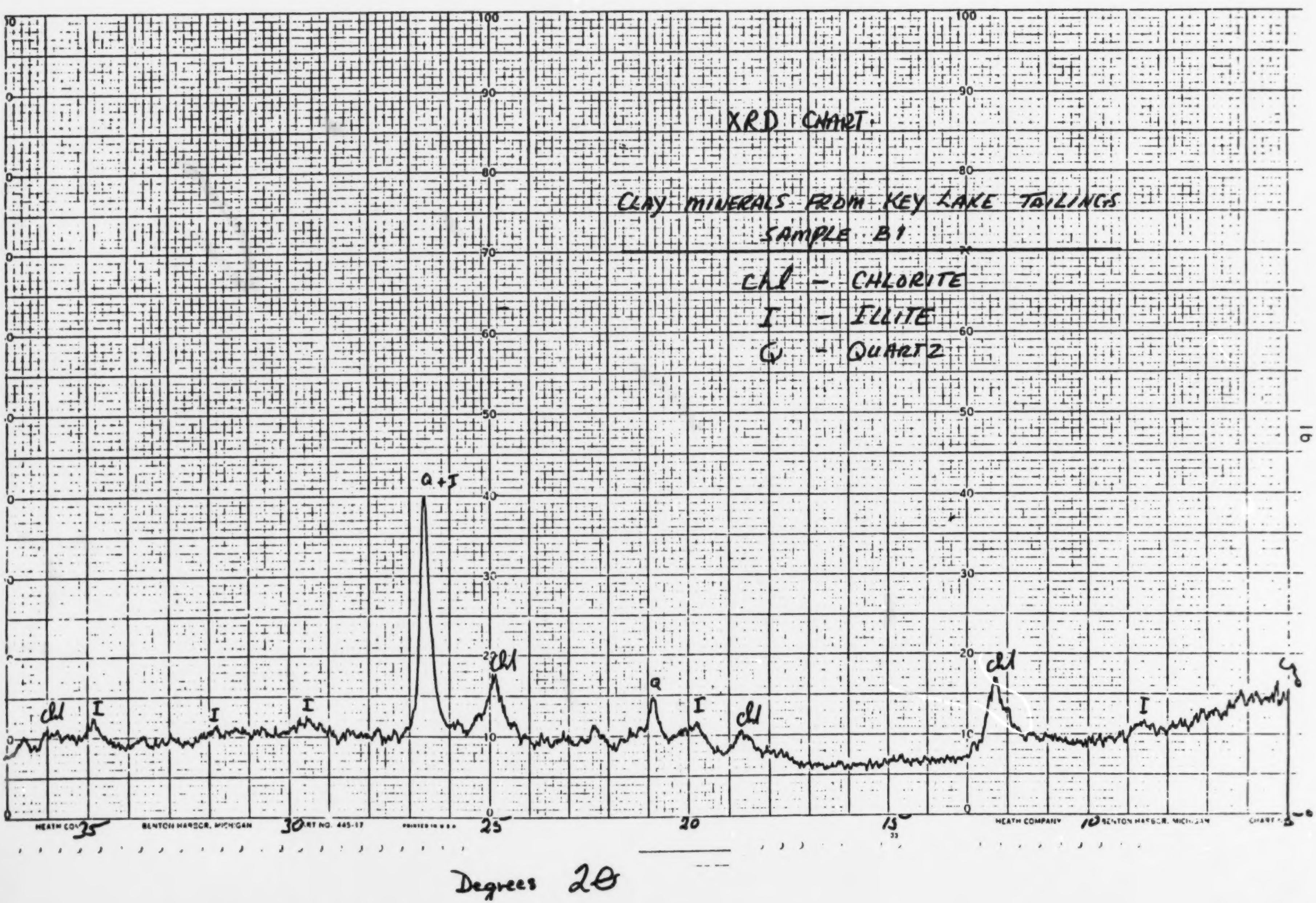


Fig. 5 XRD pattern of clay minerals from tailings.

APPENDIX D2

REPORT ON FROZEN AND NON-FROZEN KEY LAKE TAILINGS SAMPLES BY SASKATCHEWAN RESEARCH COUNCIL

SRC
Saskatchewan
Research Council

Memorandum

December 4, 1985

TO: Harvey Dew

FROM: Ralph Arnold

RE: Frozen and non-frozen Key Lake tailings samples

A cursory examination of the two tailings samples showed that the sample that had been frozen had a lower moisture content (drier in appearance), was more consolidated (less plastic to the touch), and produced far fewer desiccation cracks when small thin samples were dried out at room temperature.

There are two mechanisms that we could think of that might account for the different physical properties of the two samples. The first possibility involves improving particle packing, and the resultant increase in bulk density through the mechanical process of expansion and contraction induced by freeze/thaw cycling.

A second mechanism involves the effect that freezing has on the behavior of clay minerals. It has been observed by our ceramics expert that freezing slurries with a substantial clay content tends to flocculate the clays: the clay minerals agglomerate, thereby forming larger particles and releasing trapped/adsorbed water to the pore fluid.

The increased amount of pore water then freezes and drains away after thawing, given the opportunity. The pore water, as ice, would be freeze-purified leaving concentrated soluble salts in contact with clay minerals. The effect of the concentrated salts might be to aid the clay flocculation process.

The process of flocculation results in the development of clay aggregates which increases the effective particle size of the sample generally. This might help to explains why the frozen sample shows far fewer desiccation cracks when a small sample is dried. This follows the principle that coarser grained material normally develops fewer desiccation cracks when dried.

A number of SEM photographs (1.25 x 10^3) were taken of frozen and non-frozen material which shows the clay minerals rather clearly as plates of various sizes. The slabs and needles are probably gypsum. The theory of flocculation or agglomeration of the clays is not clearly supported by these photos. What is evident, but rather subtle, is that the clay particles in the frozen material are generally finer grained, and they seem to be more densely packed. Is it possible that freezing has comminuted or broken up the clay minerals?

Several SEM photos were taken at higher magnifications (5.00 x 10^3). The photo of frozen material shows the development of a few clay aggregates made up of fine grained clay particles. This might support the idea that freezing breaks up some of the clay plates into smaller pieces, which then proceed to agglomerate. The water trapped between the original clay plates is liberated in the process.

In conclusion, the consensus around here is that freezing can cause some surprising effects. Perhaps this problem would make an interesting research project for someone!

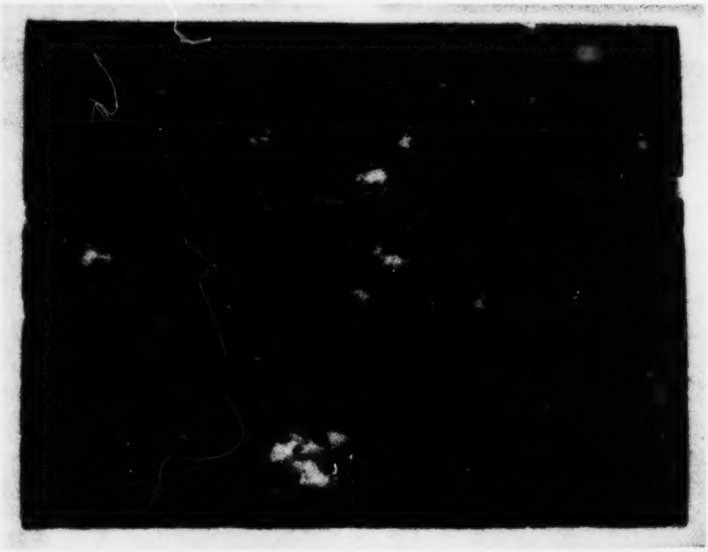
Enclosed are two pages with SEM photos and an envelope of negatives.

cc Grant Feasby (copy enclosed with the two samples).

FROZEN SAMPLE

1.25×10^3 mags.
Scale bar is 10 microns.

This material looks somewhat finer grained and more densely packed, as compared to the non-frozen sample.



1.25×10^3 mags.
Scale bar is 10 microns.

This material looks somewhat finer grained and more densely packed, as compared to the non-frozen sample.

5.00×10^3 mags.
Scale bar is 10 microns.

NON-FROZEN SAMPLE

1.25 x 10^3 mags.
Scale bar is 10 microns.

This material looks somewhat coarser grained and not so densely packed as compared to the frozen sample.

1.25 x 10^3 mags.
Scale bar is 10 microns.

This material looks somewhat coarser grained and not so densely packed as compared to the frozen sample.

5.00 x 10^3 mags.
Scale bar is 10 microns.

APPENDIX E

REPORT ON SIZE DISTRIBUTION OF URANIUM TAILINGS
BY B.H. LEVELTON AND ASSOCIATES

B.H.
EVELTON & ASSOCIATES LTD.

8805 OSLER STREET
VANCOUVER, B.C. CANADA V6P 4G1
(604) 266-1411 - TELEX 04-55581

September 19, 1985

File: 4-85-693

Knight and Piesold Ltd.
1350 United Kingdom Building
409 Granville Street
Vancouver, B.C.
V6C 1T2

Attention: Mr. J.P. Haile, P.Eng.

Dear Sirs:

1603.22

Re: Size Distribution of Uranium Tailings

We have completed initial aspects of work on the tailings sizing. As you are aware by now, the tailings would not disperse by any conventional methods including ultrasonic agitation, wetting dispersants and combinations of these. The problem arose from the presence of the large amount of calcium sulfate present which formed a matrix preventing particle dispersion. We finally found that treating the tailings with 5% hydrochloric acid release the particles.

The analysis of the two samples submitted are:

Sample No.	B1	B4 (not B2)
Lab No.	807	808
+200 mesh (wt%)	1.6	1.5
-200 +325 mesh (wt%)	14.0	35.0
-325 but retained on 0.45 um filter paper (wt%)	32.8	18.4
total retained on 0.45 um filter	48.4	54.9

Note that of the original samples, only 48.4 and 54.9% are retained on the filter. Since the -200 mesh material in slurry was treated with acid, it is reasonable to assume the calcium sulfate was desolved and represents 45 to 50% of the sample weight. There is a danger in making such an assumption because some clay minerals are fairly soluble in hydrochloric acid.

September 19, 1985

Photographs 1 through 8 show the appearance of untreated and treated clay slurries. The particle size range is clearly shown.

We have stopped work at Mr. Dew's request of September 11, 1985.

Yours very truly,

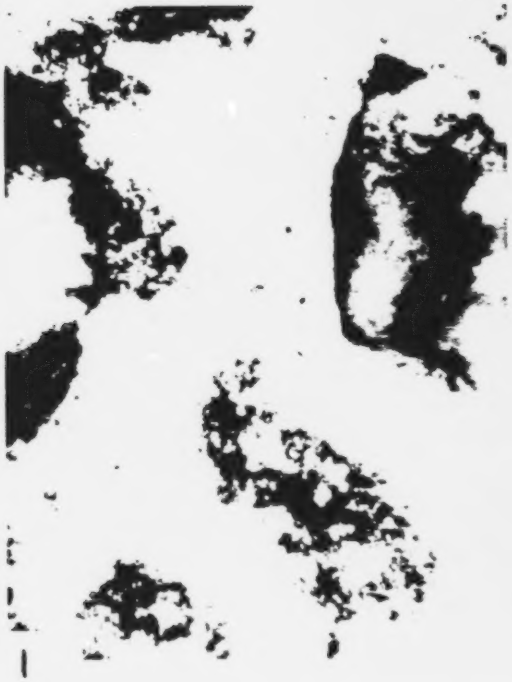
B.H. LEVELTON & ASSOCIATES LTD.

B.H. Levelton, P.Eng.

BHL/ft

Encl.

PICTURE	SAMPLE	MESH	MAGNIFICATION
1	B1	as rec'd	X165
2	B4	as rec'd	X165
3	B1	200-325	X165
4	B4	200-325	X165
5	B1	as rec'd fines	X660
6	B4	as rec'd fines	X660
7	B1	-325	X660
8	B4	-325	X660



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APPENDIX F

REPORT ON THERMAL ANALYSES
BY B.C. RESEARCH

BC
RESEARCH

3650 Wesbrook Mall,
Vancouver, B.C.,
Canada V6S 2L2
Phone (604) 224-4331
Cable RESEARCHBC
Telex 04-507748

October 22, 1985
File: 4-04-868

T.W.
L.N.

Mr. Harvey Dew
Knight and Piesold Ltd.,
Consulting Engineers
1350 United Kingdom Bldg.
409 Granville St.
Vancouver, B.C.
V6C 1T2

1603 22

Dear Mr. Dew,

Re: Key Lake Tailing - Thermal Analysis

We have completed the authorized test program on four samples provided. In summary, thermal analysis indicates that bound water in the form of gypsum (calcium sulphate dihydrate, $CaSO_4 \cdot 2H_2O$) is the only identifiable form of chemically bound water. Thermogravimetric analyses under a range of conditions indicate that a heating rate of 2°/minute gives adequate discrimination between free water and gypsum bound water.

As a percentage of ambient temperature vacuum dry weight identified (gypsum) bound moisture contents of the four samples ranged from 4.0% to 5.9%. Free moisture contents of samples after overnight vacuum drying at 40°C were in the range of 2.6 - 10.4%

Differential Scanning Calorimitry (DSC) test results indicate significant endotherms attributed to free moisture and gypsum only.

TGA results for jarosite (basic ferric sulphate) and montmorillonite clay do not appear to correlate with TGA data on the samples provided.

Details of procedure and results are as follows:

Technical Operation of the
BRITISH COLUMBIA
RESEARCH COUNCIL,
a Non-profit Industrial
Research Society

1.0 Sample Preparation

Test samples provided were initially air dried, crushed and split. Riffled subsamples were then vacuum dried overnight at ambient temperature (19-23°C).

2.0 Thermal Analysis

All thermal analyses were performed on a Dupont 1080 unit with DSC and TGA modules.

3.0 Results and Discussion

3.1 Gross Moisture Content

Moisture losses on air drying of as-received samples were:

Sample	Moisture (% as received)
A2	57.3%
A3	60.7
B2	44.0
B3	49.9

Overnight ambient temperature vacuum drying removed a further 1-2% of free moisture.

3.2 TGA Tests

3.2.1 Variation of Conditions

Sample A-2 was arbitrarily selected for evaluaton of the effect of variation in TGA test conditions. Results are summarized in Table 1; machine plots (weight and temperature vs time) are presented as Figures 1-4.

Results of tests with nitrogen and argon gas purge (Figures 1 and 2) show no difference in behaviour, indicating - as expected - that nitrogen is an inert atmosphere for the test.

In a test (Figure 3) with a 30 minute hold at 80°C, sample weight did not completely stabilize, and free moisture (9%) was slightly less than the 9.9% value in a 2 degree/minute continuous heating test (Figure 2). A hold at T >80°C was considered too close to the nominal decomposition temperature of gypsum. Thus tests at a 2°/minute heating rate are considered to offer a reasonably optimal method for distinguishing between free moisture and gypsum hydration water. A 10°/minute heatrate (Figure 4) still allows reasonable discrimination between moisture and water of hydration, but shows a much higher nominal gypsum dehydration temperature.

Qualitatively, Figures 1-3 show onset of weight loss at ~30°C and steady continuation to 80-90°C at the low heating rate of 2°/minute; this is considered to indicate physically associated water. The result is also - in theory at least - compatible with a very poorly defined hydrous iron precipitate. However, the temperature range of weight loss is so broad that for practical purposes this weight loss can be regarded as free moisture. (It should be noted that weight losses up to at least the end of gypsum dehydration (~120°C) are assumed to be water only; this is considered to be a reasonable assumption on the basis of the bulk composition shown in Appendix 1.

3.2.2 TGA Free and Bound Water Data

Data on "free" and gypsum bound water contents of vacuum dried material are presented in Table 2.

Machine printouts are presented as Figures 1 and 5-7; for reference purposes, printouts for gypsum, jarosite and montmorillonite clay are shown as Figures 8-10.

With respect to free moisture, there appear to be significant differences among the samples. The range is 2.6-11.3 wt % which is certainly beyond the range of analytical uncertainty. Also, for Sample A2 there was neglibible differences between a sample vacuum dried for 2 h (10.36% free moisture) and one dried overnight (9.9%, 10.1% at 2°/minute, 9.0% with an 80°C hold).

This apparent differnce in free moisture does not correlate with gypsum bound moistures (Table 2) which are in the 4.3-5.8 wt% range - ie. 20.5-27.7 wt % gypsum in the vacuum dried material.

The poorly defined high temperature weight losses presented in Table 2 show an analytically significant degree of variation between the A2, A3 samples (5.9 and 5.4% respectively) and B2, B3 samples (4.1 and 4.0% respectively).

Qualitatively, as discussed below in relation to DSC results, all four samples show a fairly steady weight loss in the 200-600°C range with no well defined transition.

Current results do not allow attribution of the 4-5% +200°C weight losses exclusively to loss of bound water since the temperature range covers the zone of pyrite decomposition (roughly 400-450°C) as well as allowing possible oxidation reduction reactions (eg. arsenate → arsenite; sulphate → SO_2).

Relatively large quantities of well crystallized material such as jarosite (basic ferric sulphate) can be readily characterized as shown by the graph of Figure 9.

On this basis, it is considered that the +200°C weight loss behaviour cannot be attributed specifically to loss of bound water or to any one - or even a few - specific decomposition reactions.

3.3 DSC Results

DSC plots for the test samples are presented as Figures 11 - 14; corresponding plots for pure gypsum, and for an artificial gypsum - clay (montmorillonite) - moisture mixture are presented as Figures 15 and 16.

These data show clearly defined endotherms for free moisture and two stages of gypsum dehydration; no other usefully resolved endotherms are present.

Note that in comparing the pure gypsum and test sample curves, a temperature offset is required due to loss of free moisture from the test samples. This is clearly shown by comparison of Figures 15 and 17, although the free moisture endotherm for the montmorillonite - gypsum mixture has more overlap with the gypsum → hemihydrate endotherm than is observed for test samples.

For all the test samples there is a minor and poorly defined exotherm at about 350°C. This does not correspond to any notable feature of the TGA data and could be related to a phase change.

4.0 Conclusion

TGA allows determination of free moisture and gypsum associated moisture in vacuum dried Key Lake tailing samples.

Weight losses of 4-5% at temperatures above the end of the gypsum - anhydrite transition - ie. roughly 200-600°C - may involve water loss. However, results of analysis suggest that observed weight loss represents the sum of several, possibly complex interactions. Thermal analysis in the present state of the art cannot differentiate reactions for the test samples in this range.

The amount of bound water loss from samples in the 200-600° range could probably be determined by careful bulk heat treatment and determination of evolved water content.

I trust that this report meets your requirements. If you have any questions, please contact me or Mrs. Skelton.

Yours very truly,

B.C. RESEARCH

R.O. McElroy
Manager Fuels Program
Chemical Technology Division

ROM/lgg

TABLE 1

EFFECT OF TGA CONDITIONS* ON SAMPLE MOISTURE LOSS BEHAVIOUR

Test Sample	Heating Rate (C°/min)	Flush Gas	Weight Losses (% vs Vacuum Dry Sample)	Attributed Reaction
A-2	2 + 20**	Argon	9.9	Free H_2O
			4.8	gypsum
			4.9	indeterminate
A-2	2 + 20*	Nitrogen	10.4	Free H_2O
			4.8	gypsum
			5.1	indeterminate
A-2	2	Nitrogen	9.0	Free H_2O
	(30 min hold at 80°C)		6.1	gypsum
A-2	10	Nitrogen	10.1	Free H_2O
			5.2	gypsum

* See also Figures 1-4.

** 2 C/min to 200°C, 20 C/min to 1000°C

TABLE 2

FREE AND GYPSUM BOUND MOISTURE CONTENTS OF TEST SAMPLES

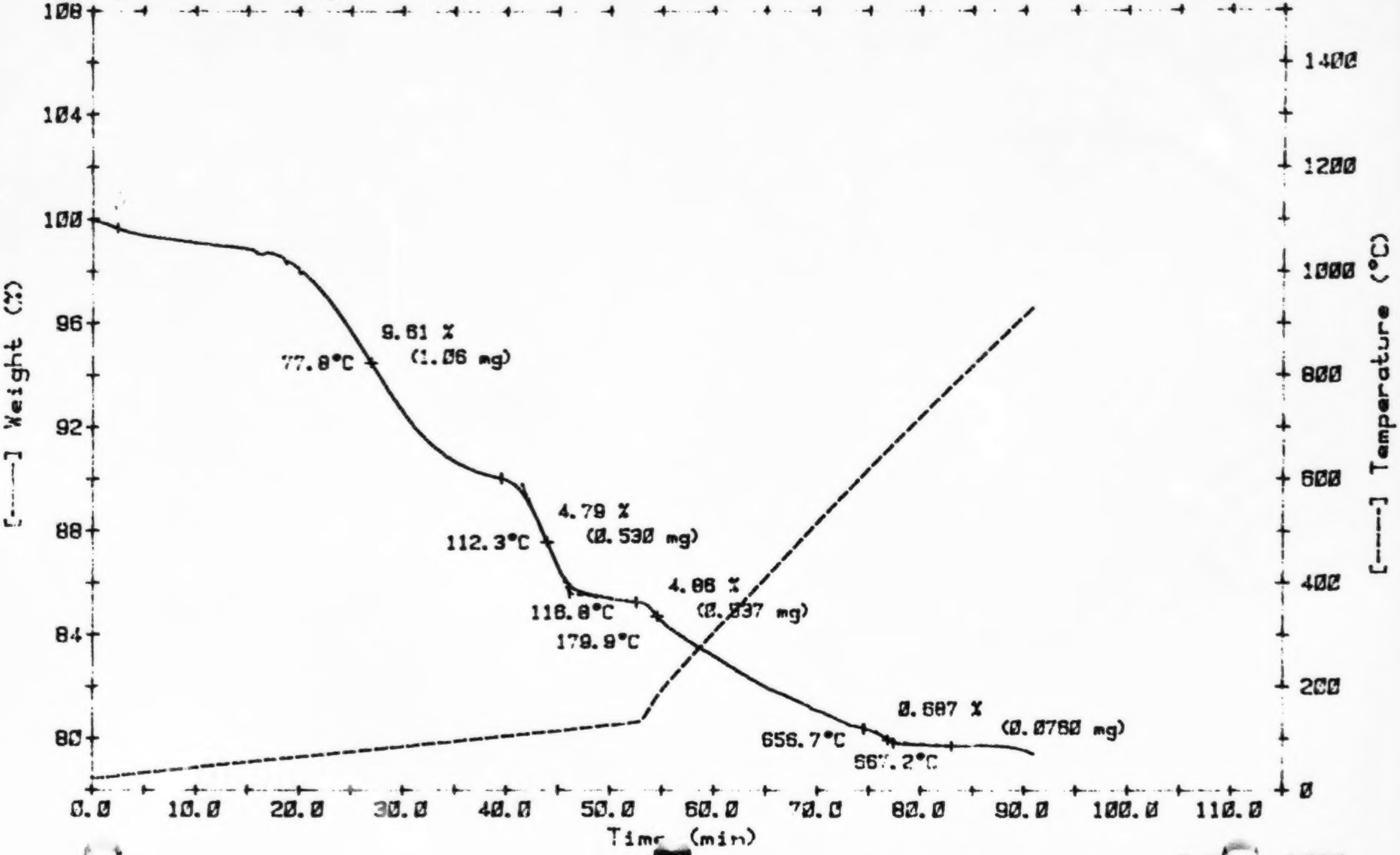
Sample	Moisture (% vs Vacuum Dry Sample)		Indeterminate +200°C loss
	Free	Gypsum Dehydration	
A2	10.4	4.8	5.9 (to 700°C)
A3	11.3	4.7	5.4 (to 690°C)
B2	2.6	4.5	4.1 (to ~600°C)
B3	5.1	4.3	4.0 (to 600°C)

Figure 1

Sample: K+P A2 vac dried overnight
Size: 11.06 mg
Rate: 2+20 DEG/MIN IN ARGON
Program: TGA Analysis V1.0

TGA

Date: 2-Oct-85 Time: 8:20:36
File: K+P.21 MISC TESTING XV
Operator: ERIN
Plotted: 2-Oct-85 9:58:20

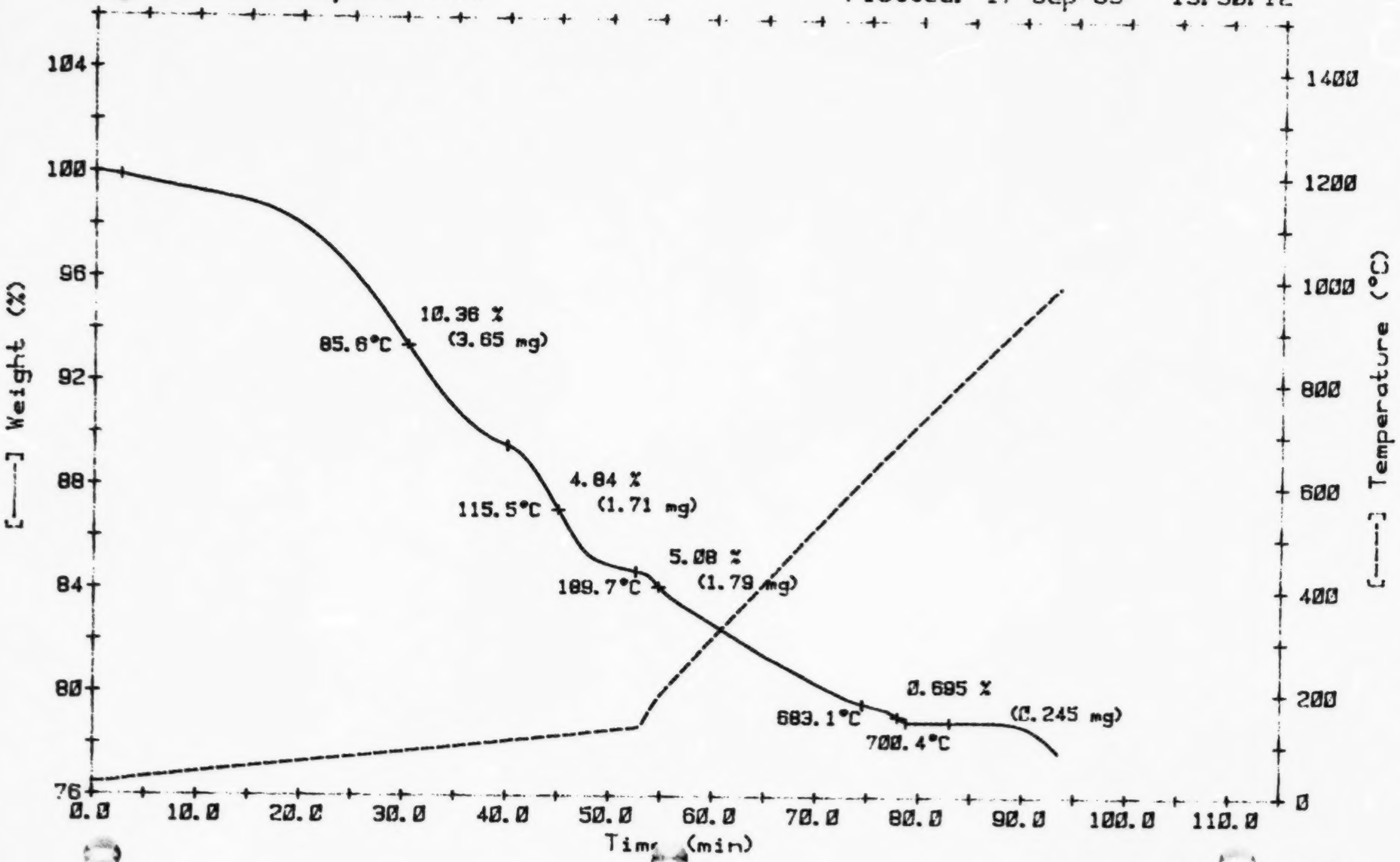


DuP[illegible] 1090

Sample: K+P A2 VAC-DRIED 2hr.
Size: 35.23 mg
Rate: 2+20 DEG/MIN IN N2
Program: TGA Analysis V1.0

Figure 2
TGA

Date: 17-Sep-85 Time: 11:22:40
File: K+P.08 MISC TESTING XV
Operator: ERIN
Plotted: 17-Sep-85 13:30:12



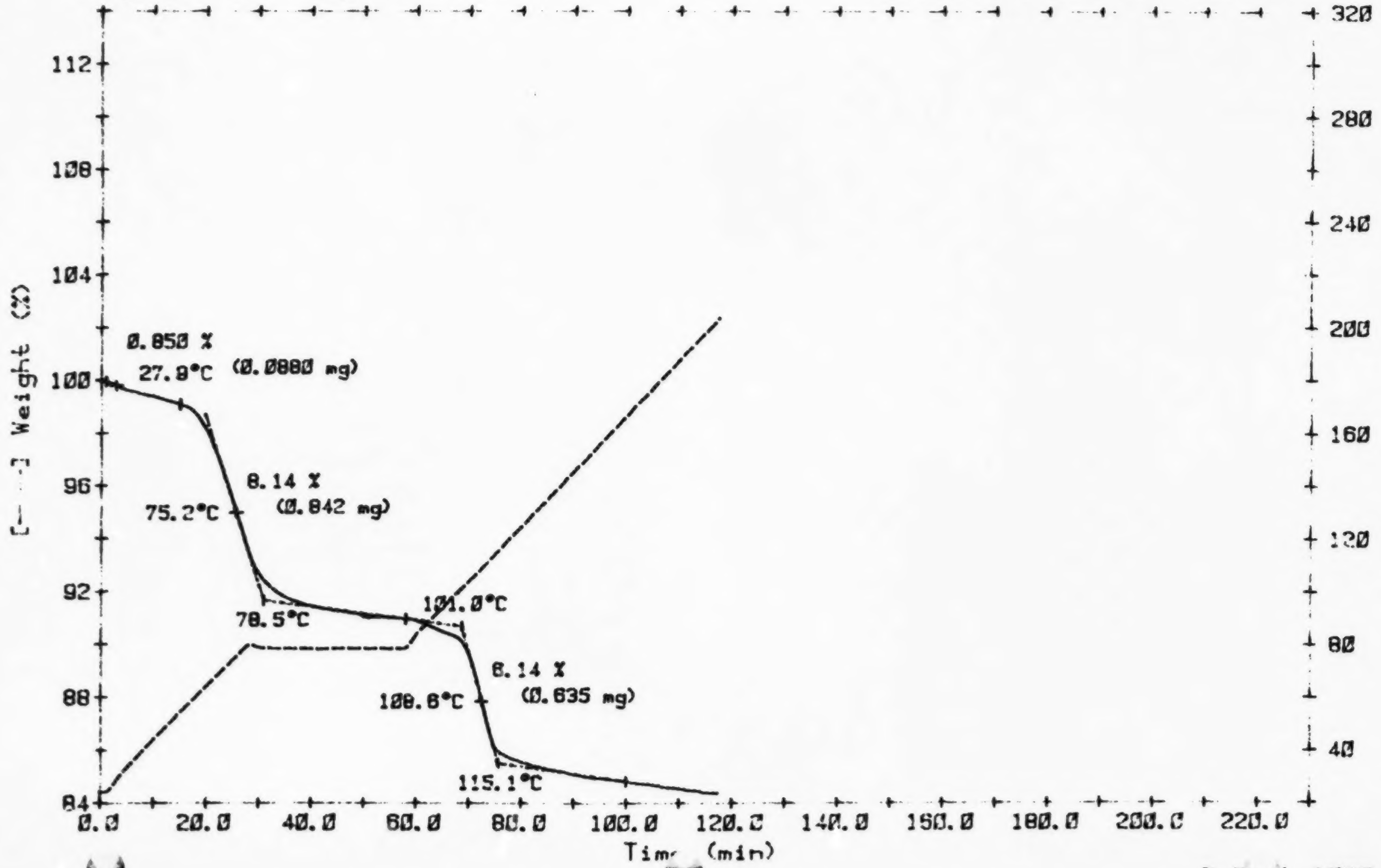
DuPont 1090

Figure 3

TGA

Sample: K+P A2 Vac [illegible]
Size: 10.35 mg
Rate: 2 DEG/MIN IN N2
Program: TGA Analysis V1.0

Date: 1-Oct-85 Time: 12:03:47
File: K+P.20 MISC TESTING XV
Operator: ERIN
Plotted: 1-Oct-85 15:54:13



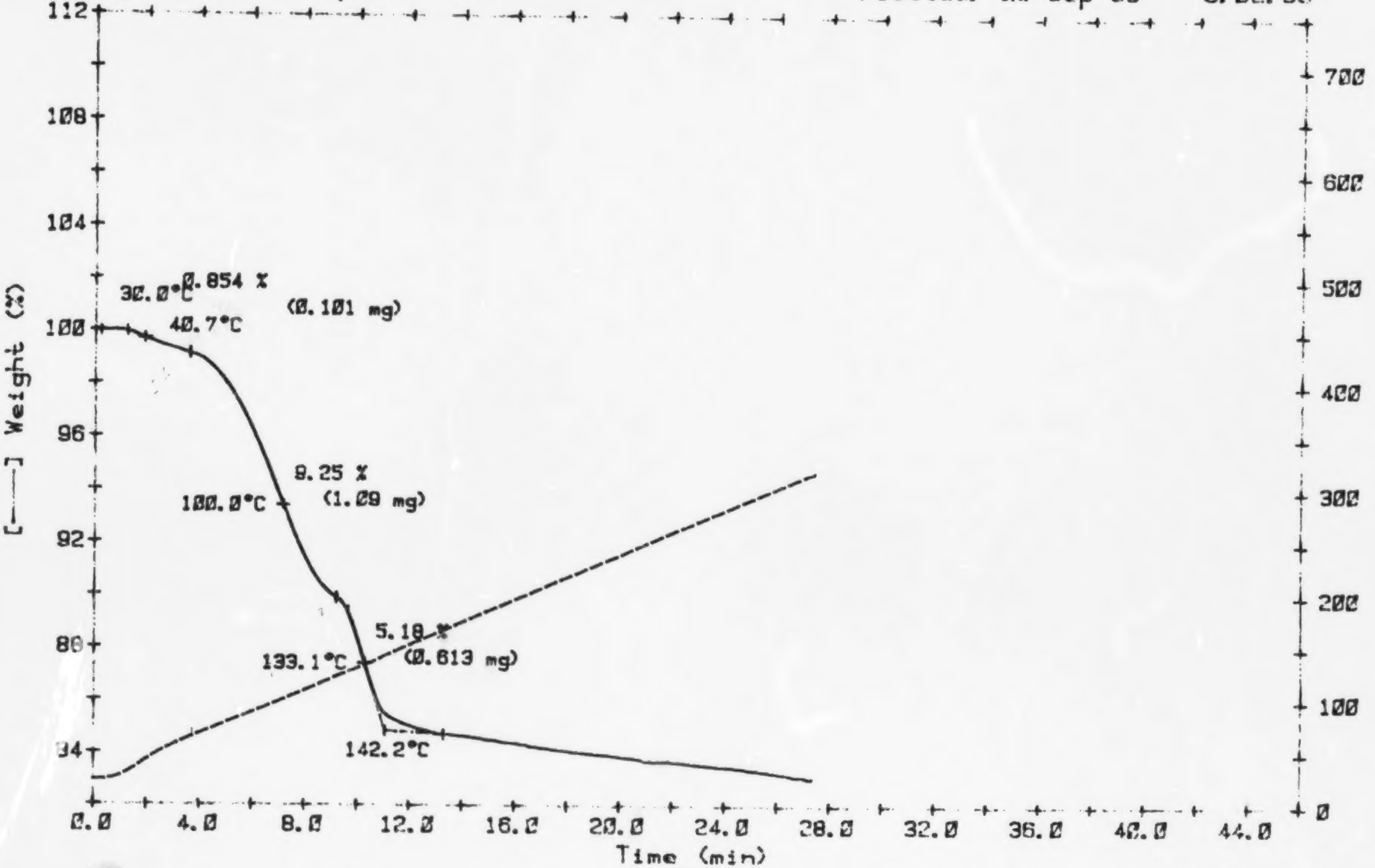
DuPont 1090

Figure 4

TGA

Sample: K+P A2 Vac dried sample
Size: 11.83 mg
Rate: 10 DEG/MIN IN N2
Program: TGA Analysis V1.0

Date: 26-Sep-85 Time: 8:30:58
File: K+P.15 MISC TESTING XV
Operator: ERIN
Plotted: 26-Sep-85 9:02:39



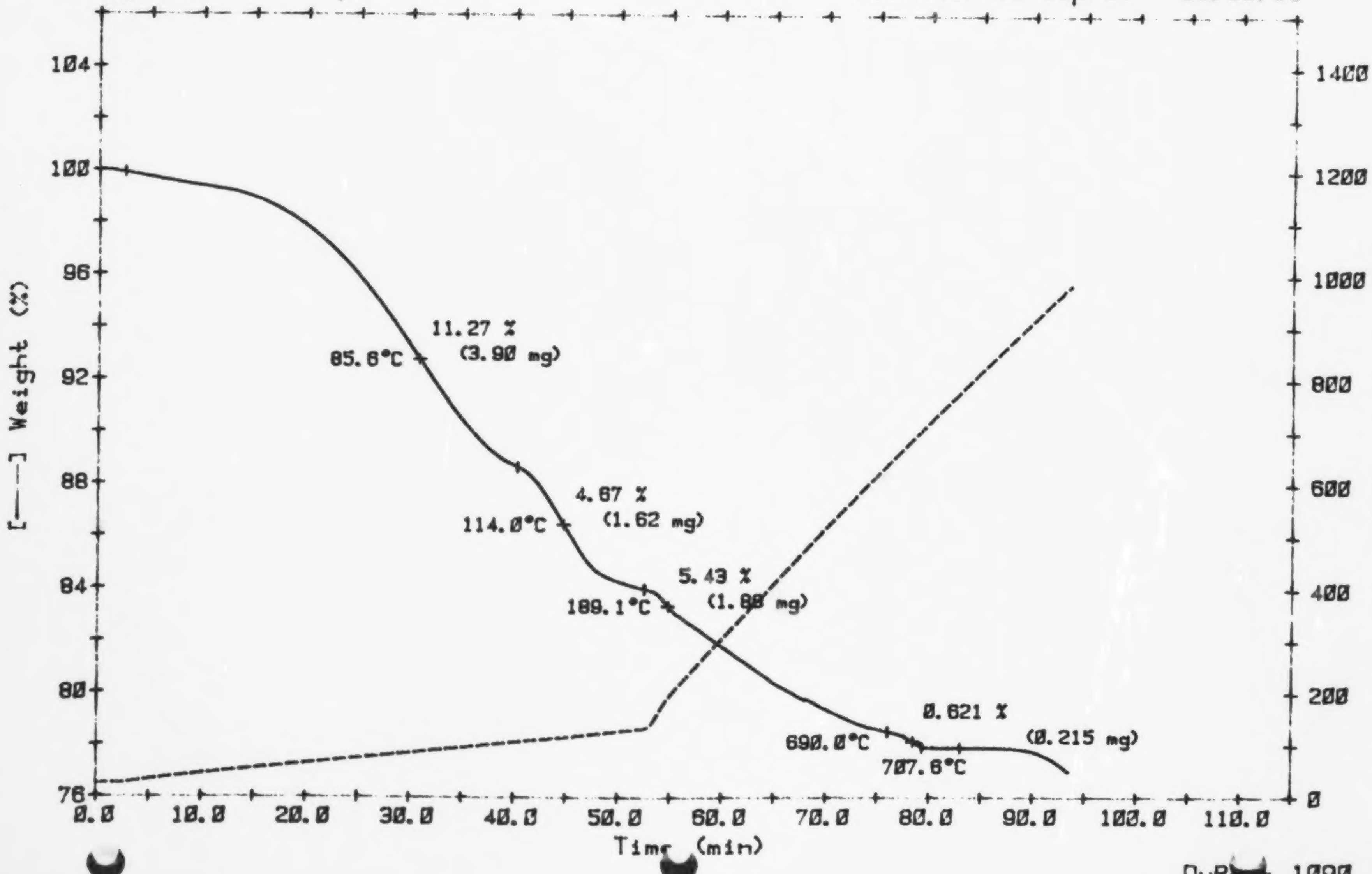
DuP[illegible] 1090

Sample: K+P A3 VAC-DRIED overnight
Size: 34.62 mg
Rate: 2+20 DEG/MIN IN N2
Program: TGA Analysis V1.0

Figure 5

TGA

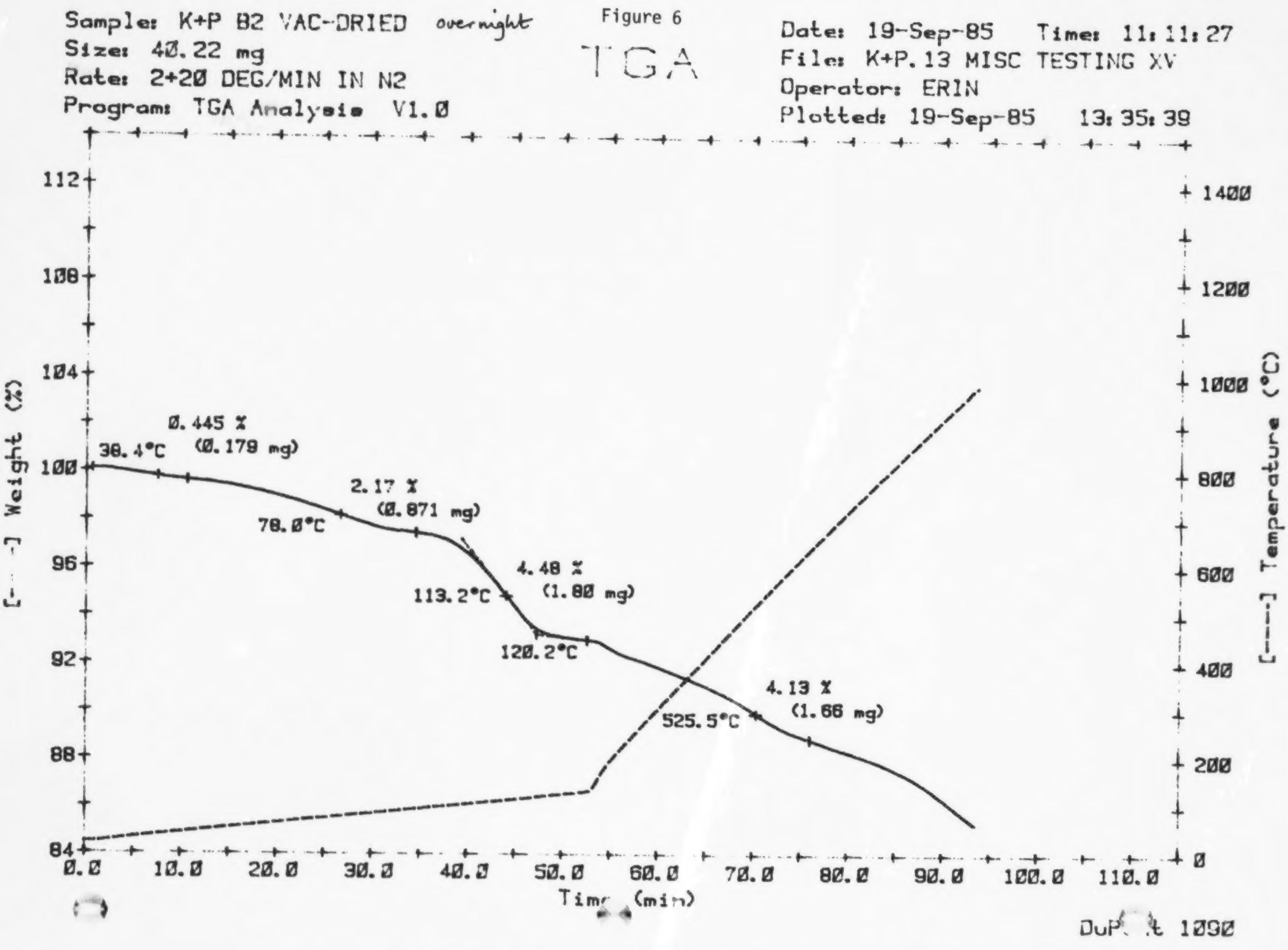
Date: 19-Sep-85 Time: 14:11:51
File: K+P.14 MISC TESTING XV
Operator: ERIN
Plotted: 19-Sep-85 15:52:31



DuPont 1090

Figure 6

TGA



Sample: K+P B2 VAC-DRIED overnight
Size: 40.22 mg
Rate: 2+20 DEG/MIN IN N2
Program: TGA Analysis V1.0

Date: 19-Sep-85 Time: 11:11:27
File: K+P.13 MISC TESTING XV
Operator: ERIN
Plotted: 19-Sep-85 13:35:39

Sample: K+P 83 VAC-DRIED overnight
Size: 37.70 mg
Rate: 2+20 DEG/MIN IN N2
Program: TGA Analysis V1.0

Figure 7

TGA

Date: 19-Sep-85 Time: 8:02:32
File: K+P.12 MISC TESTING XV
Operator: ERIN
Plotted: 19-Sep-85 9:57:32

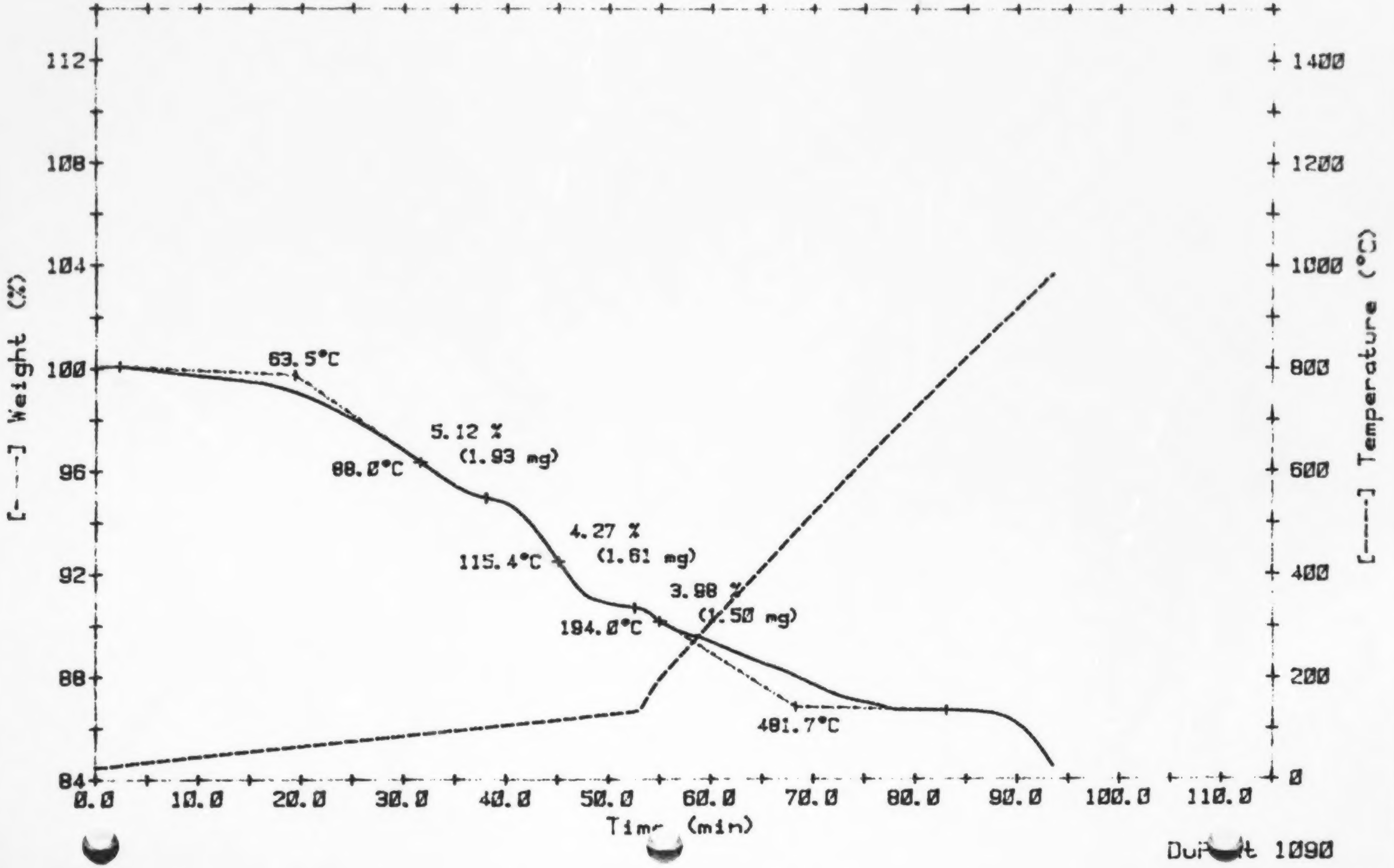
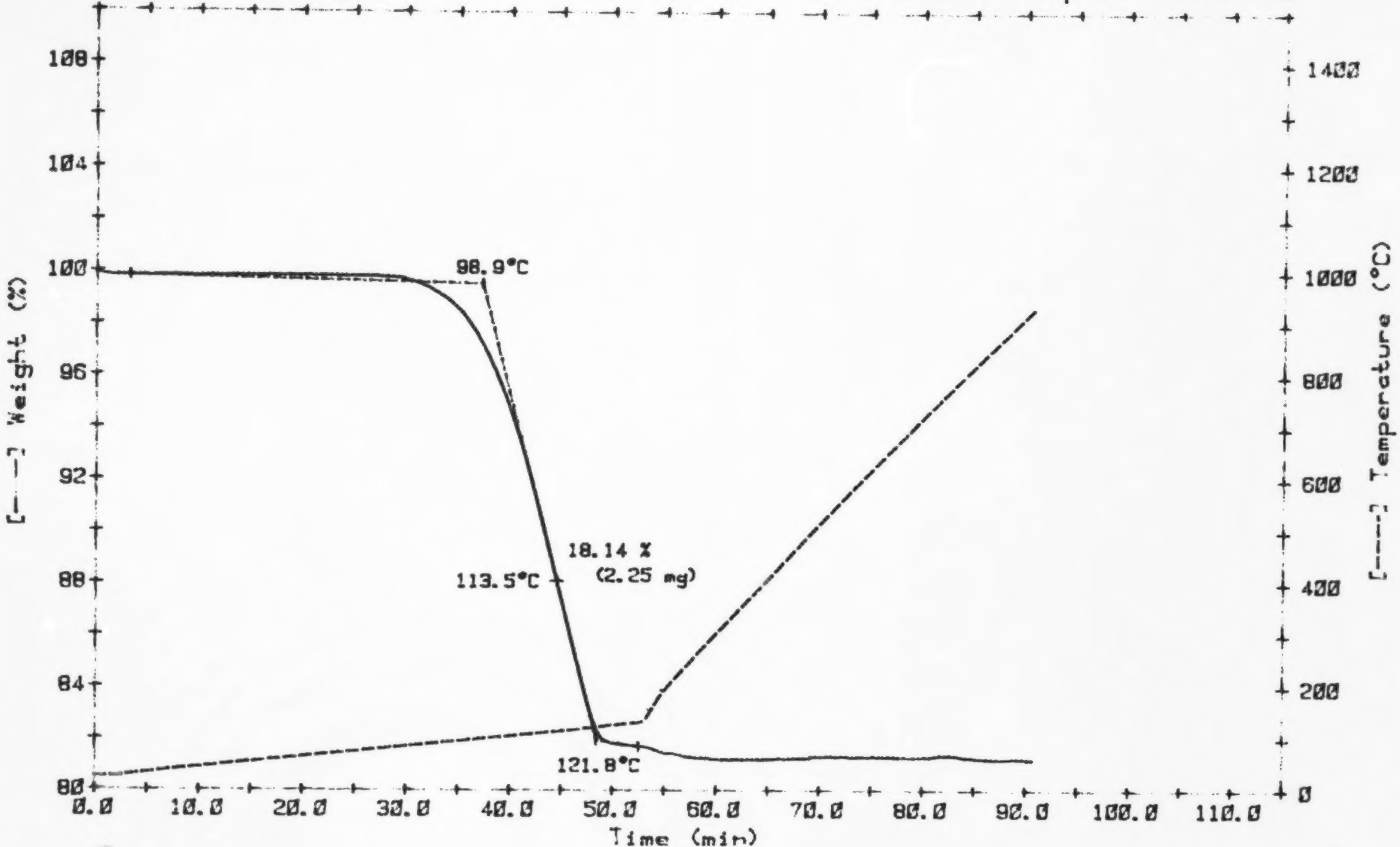


Figure 8

TGA

Sample: CA SO4 2H2O
Size: 12.41 mg
Rate: 2+20 DEG/MIN IN N2
Program: TGA Analysis V1.0

Date: 26-Sep-85 Time: 12:19:25
File: K+P.17 MISC TESTING XV
Operator: ERIN
Plotted: 26-Sep-85 14:02:01



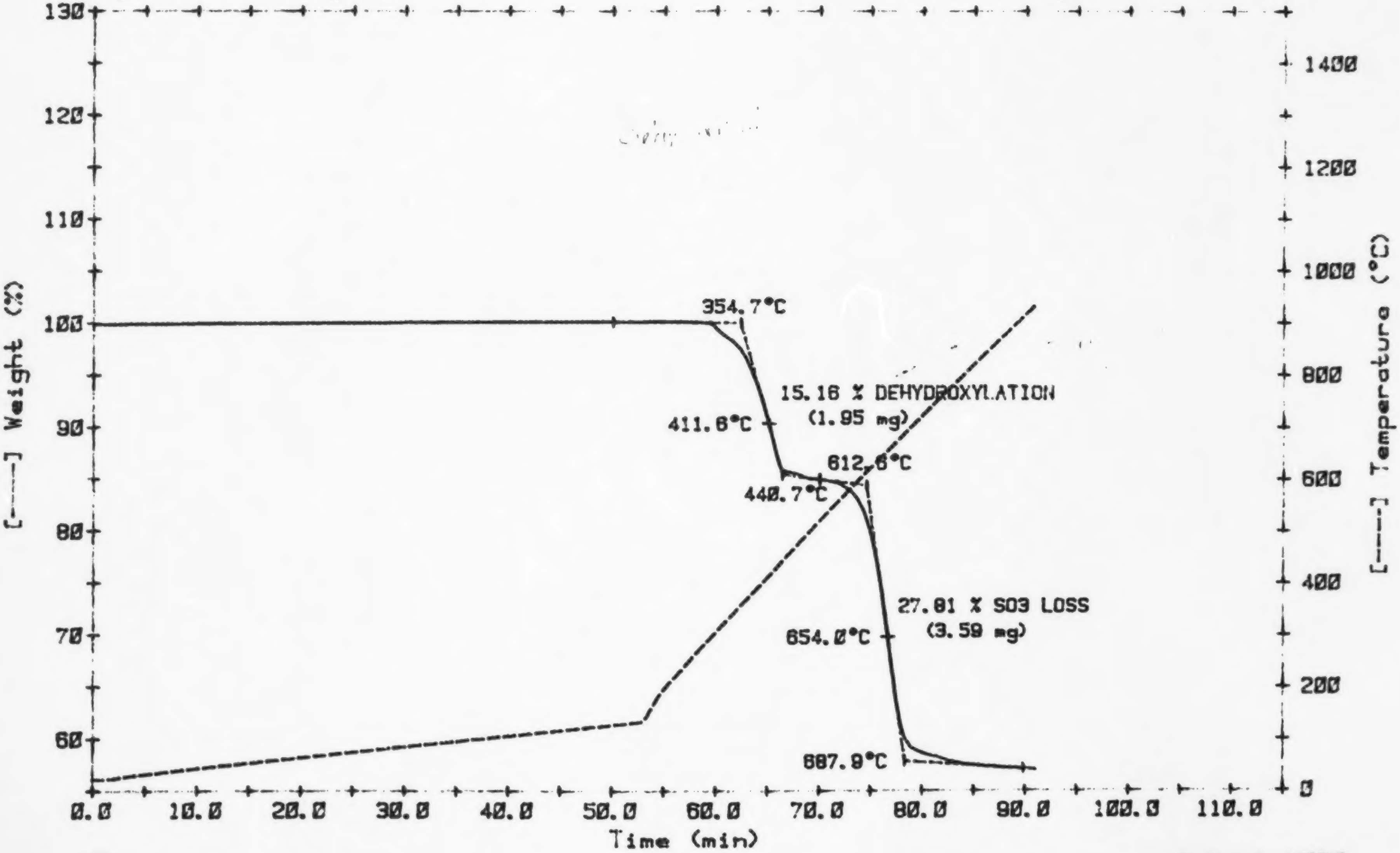
DuP[illegible] 1090

Figure 9

TGA

Sample: JAROSITE
Size: 12.89 mg
Rate: 2+20 DEG/MIN IN N2
Program: TGA Analysis V1.0

Date: 26-Sep-85 Time: 14:48:53
File: K+P.18 MISC TESTING XV
Operator: ERIN
Plotted: 26-Sep-85 16:27:41



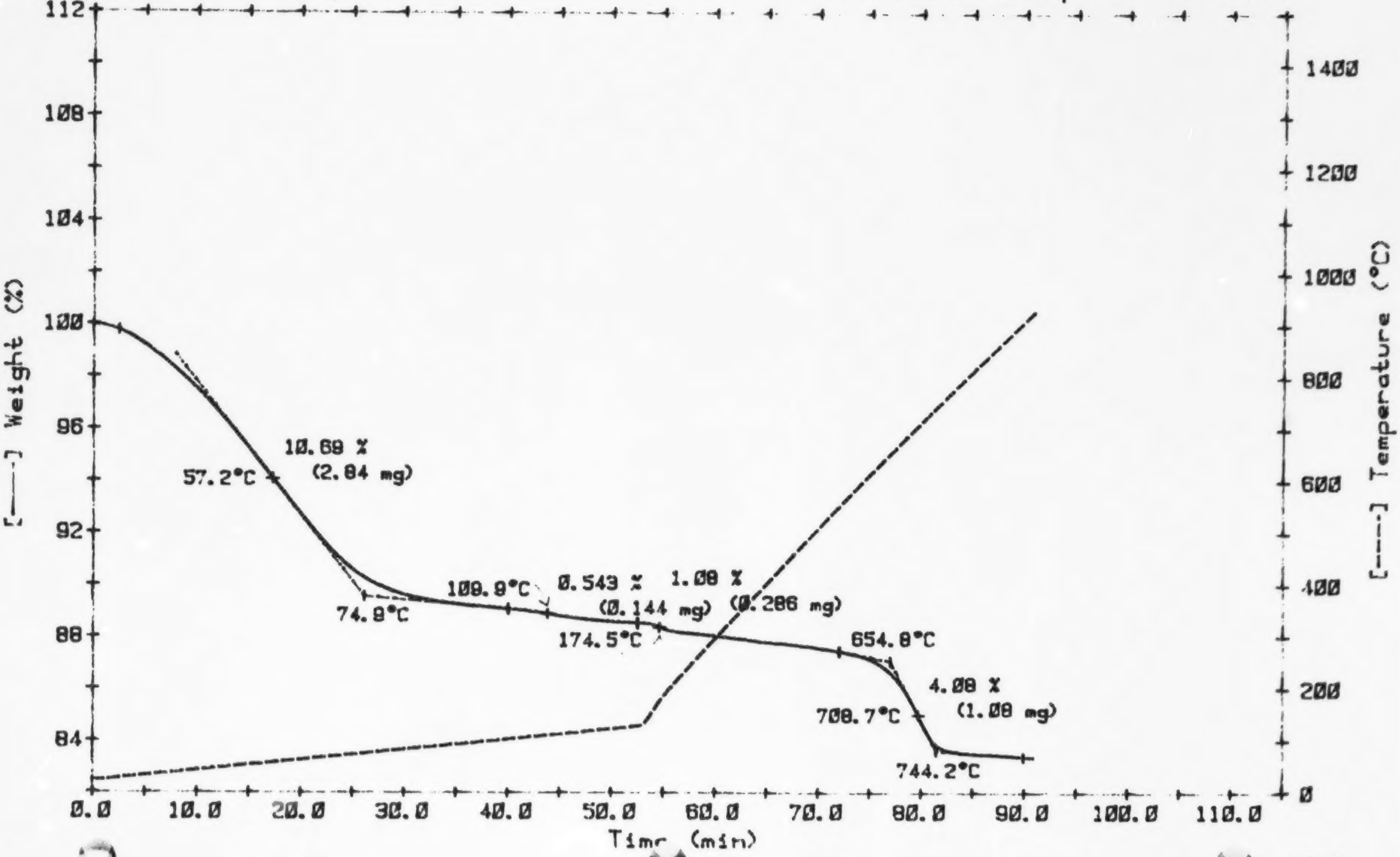
DuP t 1090

Figure 10

TGA

Sample: MONTMORILLONITE
Size: 26.54 mg
Rate: 2+20 DEG/MIN IN N2
Program: TGA Analysis V1.0

Date: 30-Sep-85 Time: 9:56:38
File: K+P.19 MISC TESTING XV
Operator: ERIN
Plotted: 30-Sep-85 11:33:01



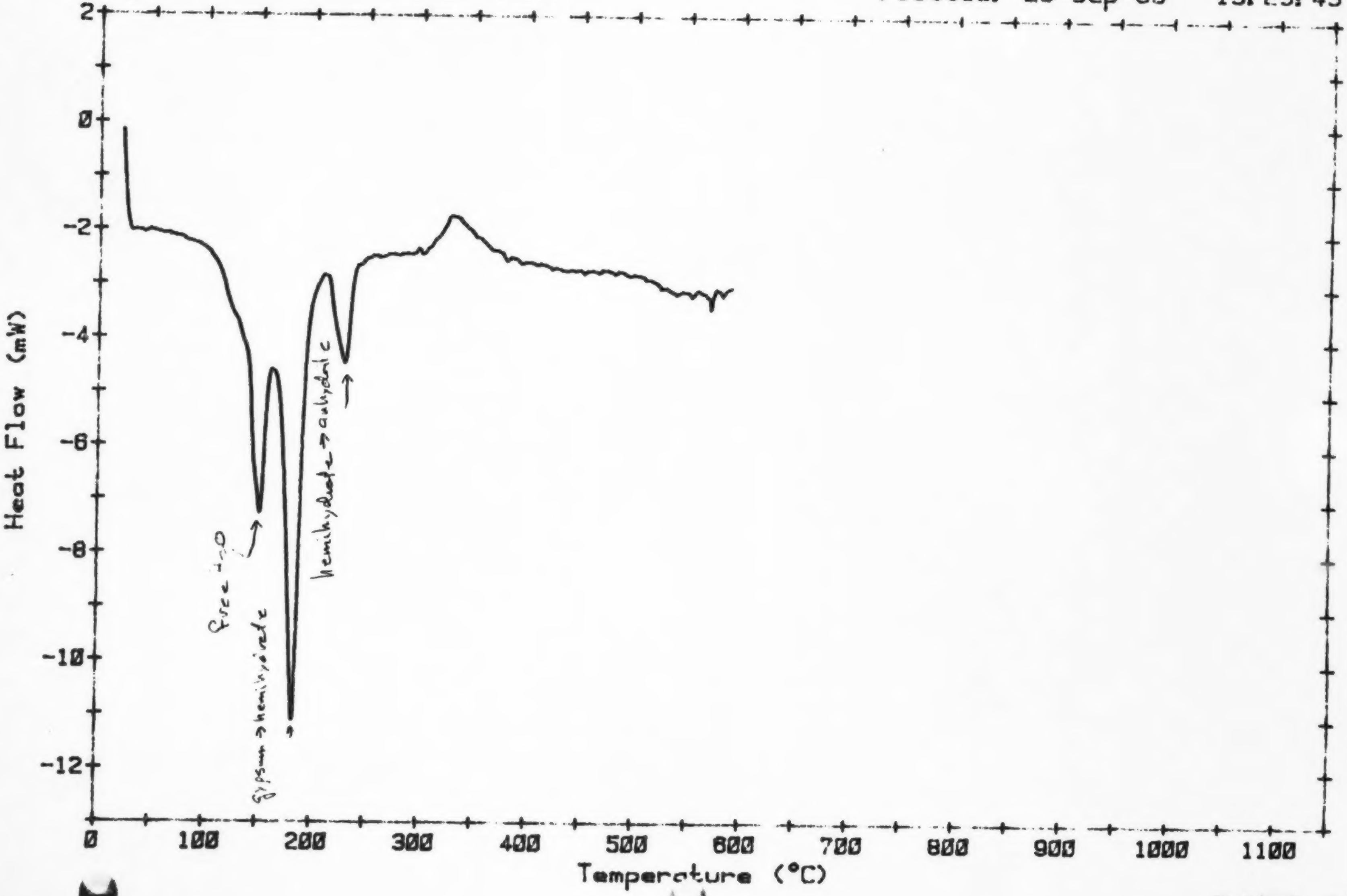
DuP t 1090

Sample: K+P A2
Size: 4.90 MG
Rate: 10 DEG/MIN IN N2
Program: Interactive DSC V2.0

Figure 11

DSC

Date: 23-Sep-85 Time: 11:31:39
File: K+P.01 DSC MISC V
Operator: ERIN
Plotted: 23-Sep-85 13:25:45



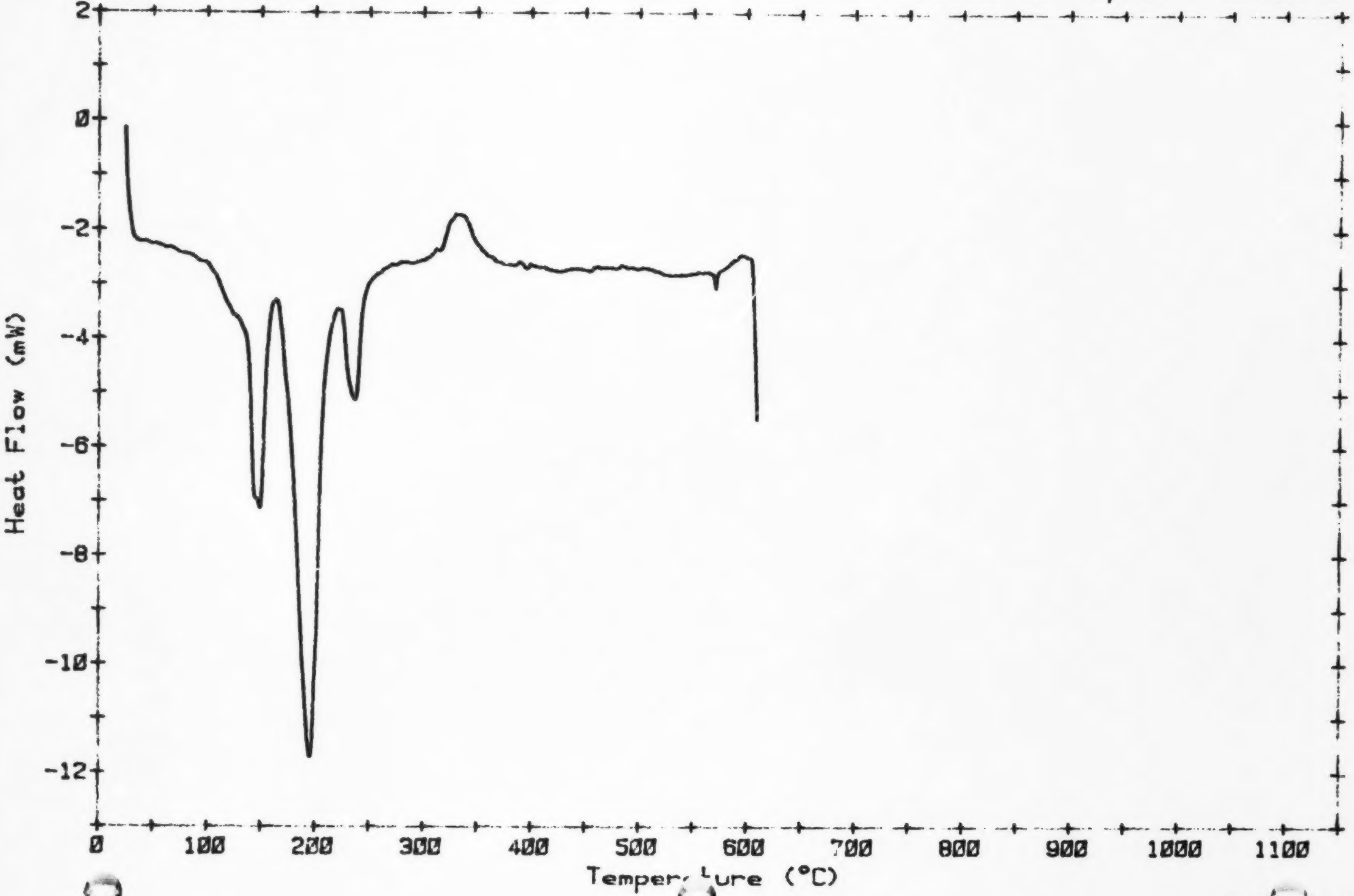
DuP t 1090

Figure 12

DSC

Sample: K+P A3
Size: 5.27 MG
Rate: 10 DEG/MIN IN N2
Program: Interactive DSC V2.0

Date: 23-Sep-85 Time: 13:51:24
File: K+P.02 DSC MISC V
Operator: ERIN
Plotted: 23-Sep-85 15:00:38



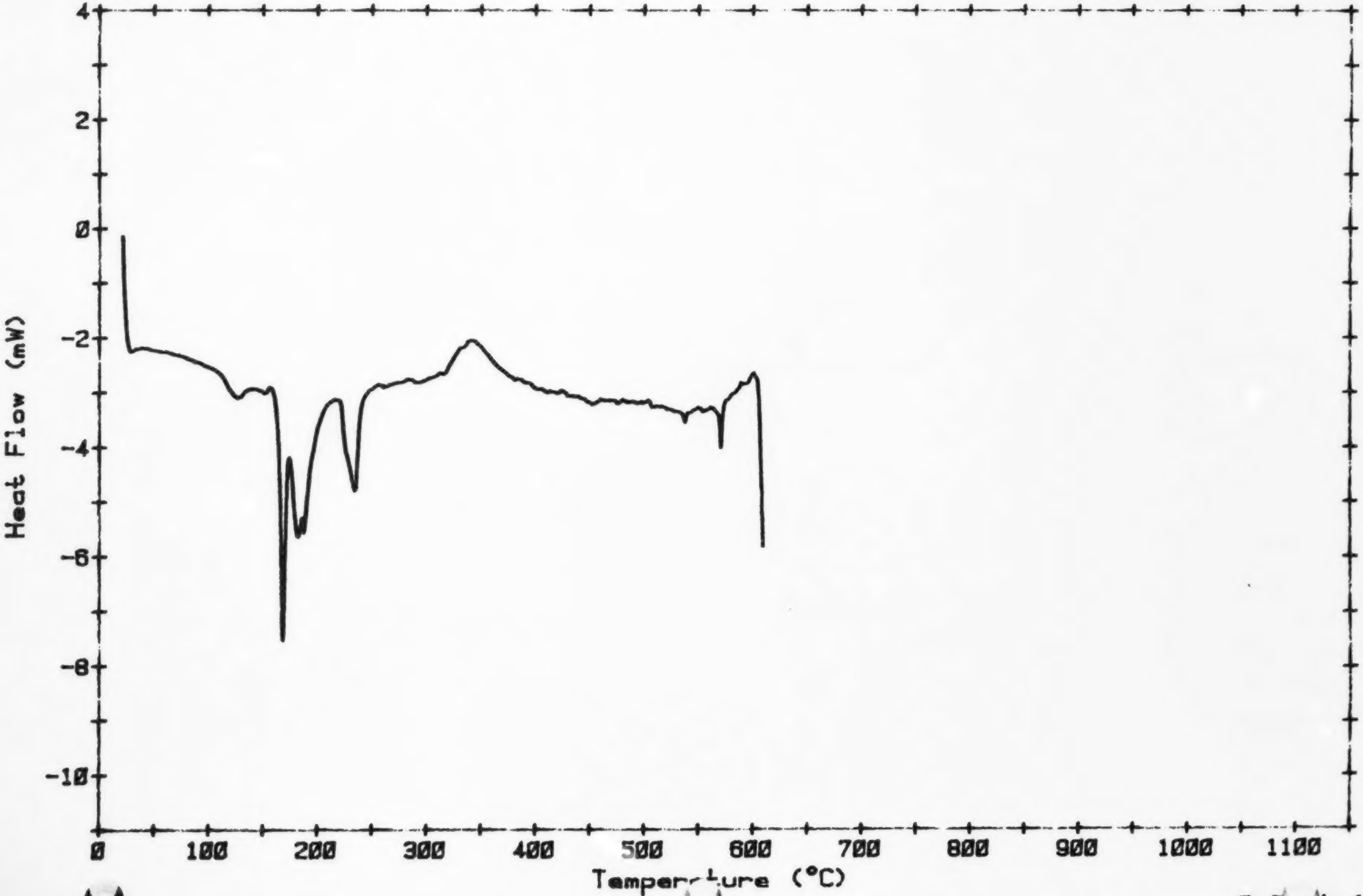
DuP t 1090

Figure 13

Sample: K+P B2
Size: 5.65 MG
Rate: 10 DEG/MIN IN N2
Program: Interactive DSC V2.0

DSC

Date: 24-Sep-85 Time: 8:02:17
File: K+P.03 DSC MISC V
Operator: ERIN
Plotted: 24-Sep-85 9:14:05



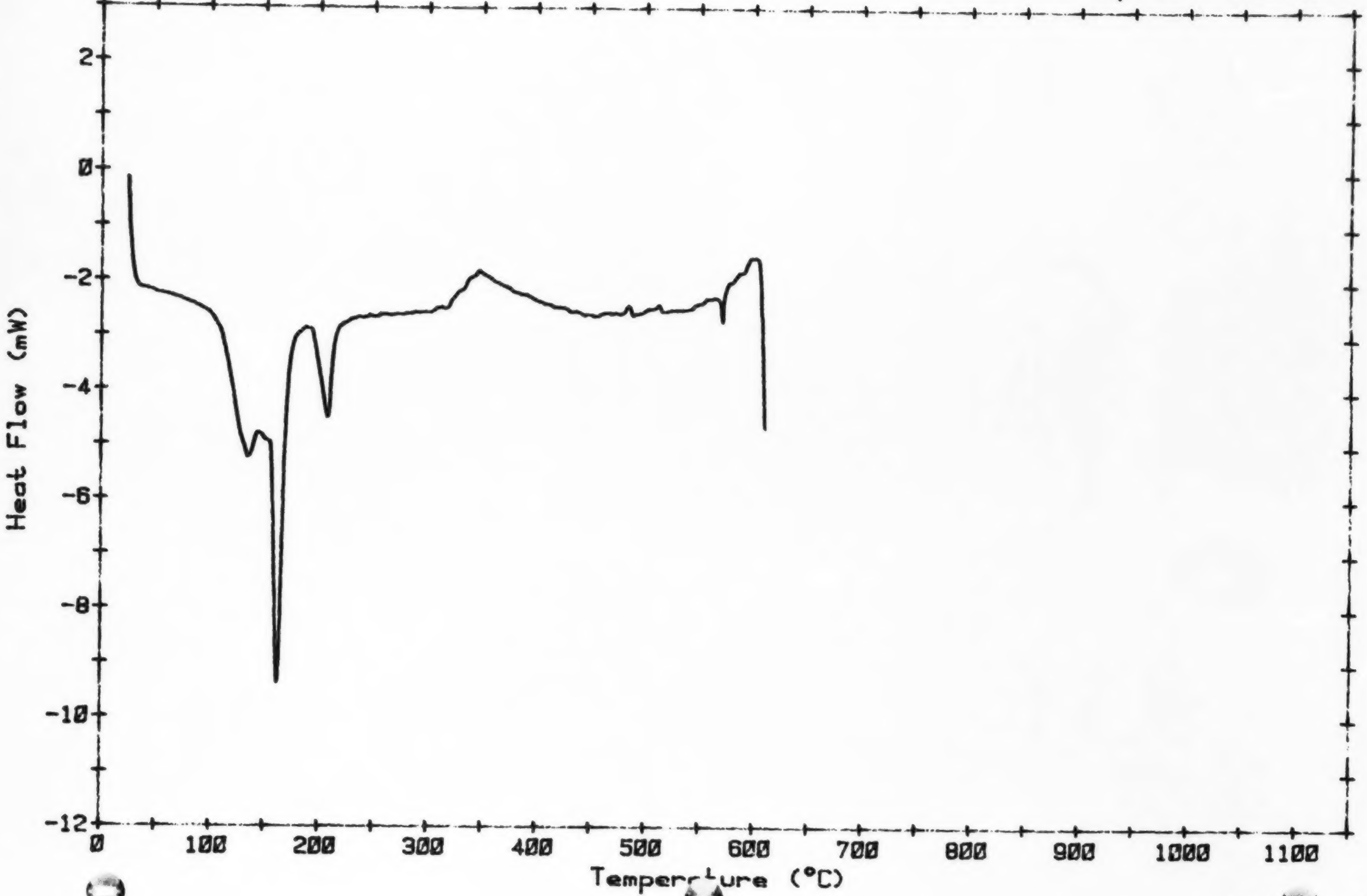
DuP t 1090

Figure 14

DSC

Sample: K+P B3
Size: 5.09 MG
Rate: 10 DEG/MIN IN N2
Program: Interactive DSC V2.0

Date: 24-Sep-85 Time: 12:05:17
File: K+P.05 DSC MISC V
Operator: ERIN
Plotted: 24-Sep-85 13:10:05



DuPont 1090

Figure 15

DSC

Sample: CA SO4 2H2O
Size: 4.34 MG
Rate: 10 DEG/MIN IN N2
Program: Interactive DSC V2.0

Date: 24-Sep-85 Time: 10:01:05
File: K+P.04 DSC MISC V
Operator: ERIN
Plotted: 24-Sep-85 11:14:28

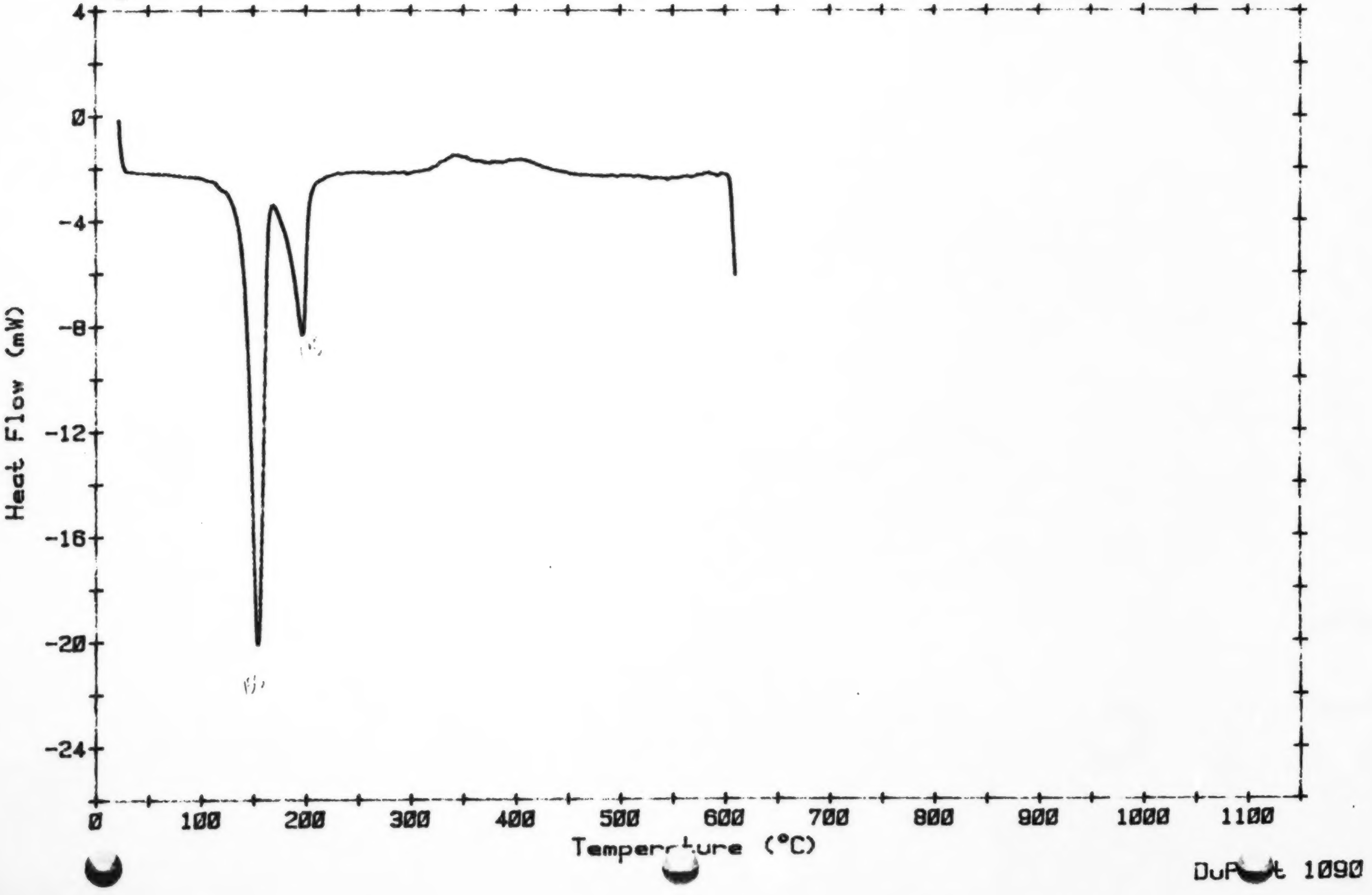
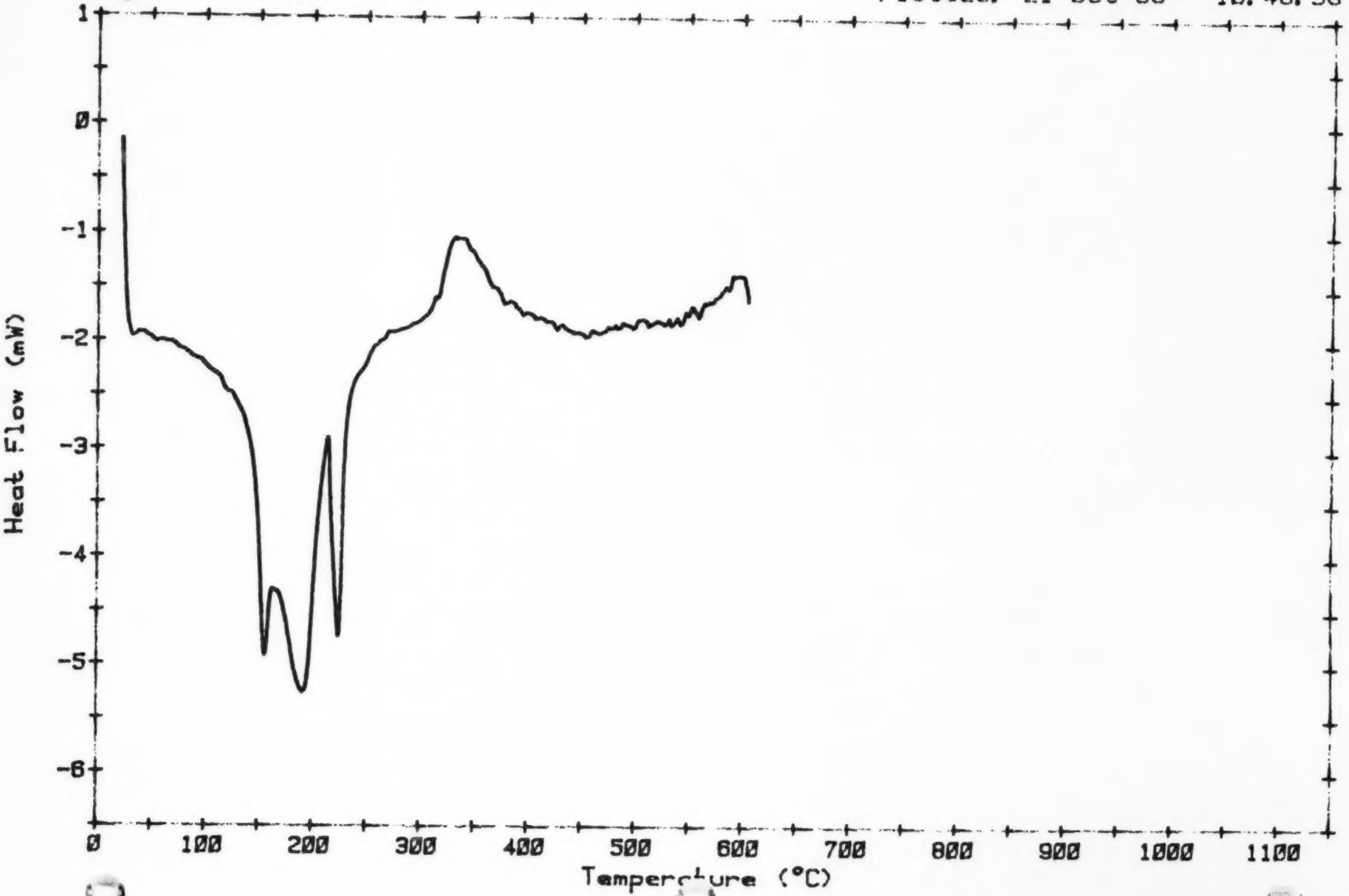


Figure 16

Sample: MONTMOR/GYPSUM-80/20
Size: 4.57 MG
Rate: 10 DEG/MIN IN N2
Program: Interactive DSC V2.0

DSC

Date: 21-Oct-85 Time: 9:36:56
File: K+P.08 DSC MISC V
Operator: ERIN
Plotted: 21-Oct-85 10:48:58



DuP t 1090

Appendix 1

Mineralogical Data Provided by Knight & Piesold Ltd.

TABLE 7.2

KEY LAKE PROJECT
MONITORING OF LAYERED URANIUM TAILINGS - PHASE I

ESTIMATED MINERALOGICAL CONTENT

Mineral/Compound	Formula	Wt. %
Major Constituents		
Quartz	SiO_2	48
Gypsum	$CaSO_4.2H_2O(2CaSO_4.H_2O)$	26
Graphite	C	2*
Illite, Trichlorite	(K, Al, Mg, Si, Ti, O, OH, Al, Mg, Si, O, OH)	7.4
Ettringite	$Ca_6Al_2(SO_4)_3(OH)_{12}.26H_2O$	3.7
Calcium Arsenate	$Ca_3(AsO_4)_2.3H_2O$	2.0
Calcite	$CaCO_3$	5.0
Gersdorffite	NiAsS	0.8
Nickel Compounds	$NiS, Ni(OH)_2\ Ni,Fe\ S_2$	2.0
Iron Compounds	$Fe_2O_3, FeS_2, Fe(OH)_3$	3.2
Minor Constitutents		
Cobalt Compounds	$CoS, Co(OH)_2$	0.1
Uranium Compounds	U(adsorbed), hydrated oxides	< .1
Zinc Compounds	$ZnS, ZnFeS, Zn(OH)_2$	< .1
Lead Compounds	$PbS, Pb(OH)_2$	< .1
Copper Compounds	$CuS, Cu(OH)_2$	< .1

Mineral/Compound	Formula	Wt. %
Trace Constituents		
Phosphates	-	< .01
V	-	< .01
Ti	-	< .01
Mn	-	< .001
Cd	-	< .001
Th	-	< .001
Mo	-	< .001
Y	-	< .001
Ba	-	< .001
Cr	-	< .001
La	-	< .001
Sr	-	< .0001
Be	-	< .0001
	TOTAL	100.2%

* assumed, no measurements available